

THE ROLE OF ENGINEERING IN THE FLIGHT EQUIPMENT PURCHASING PROCESS

Final Report

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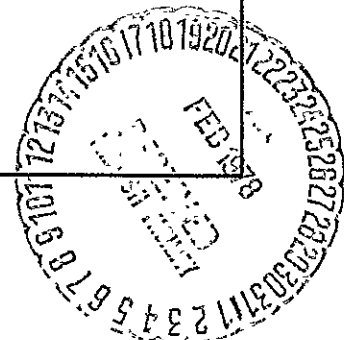


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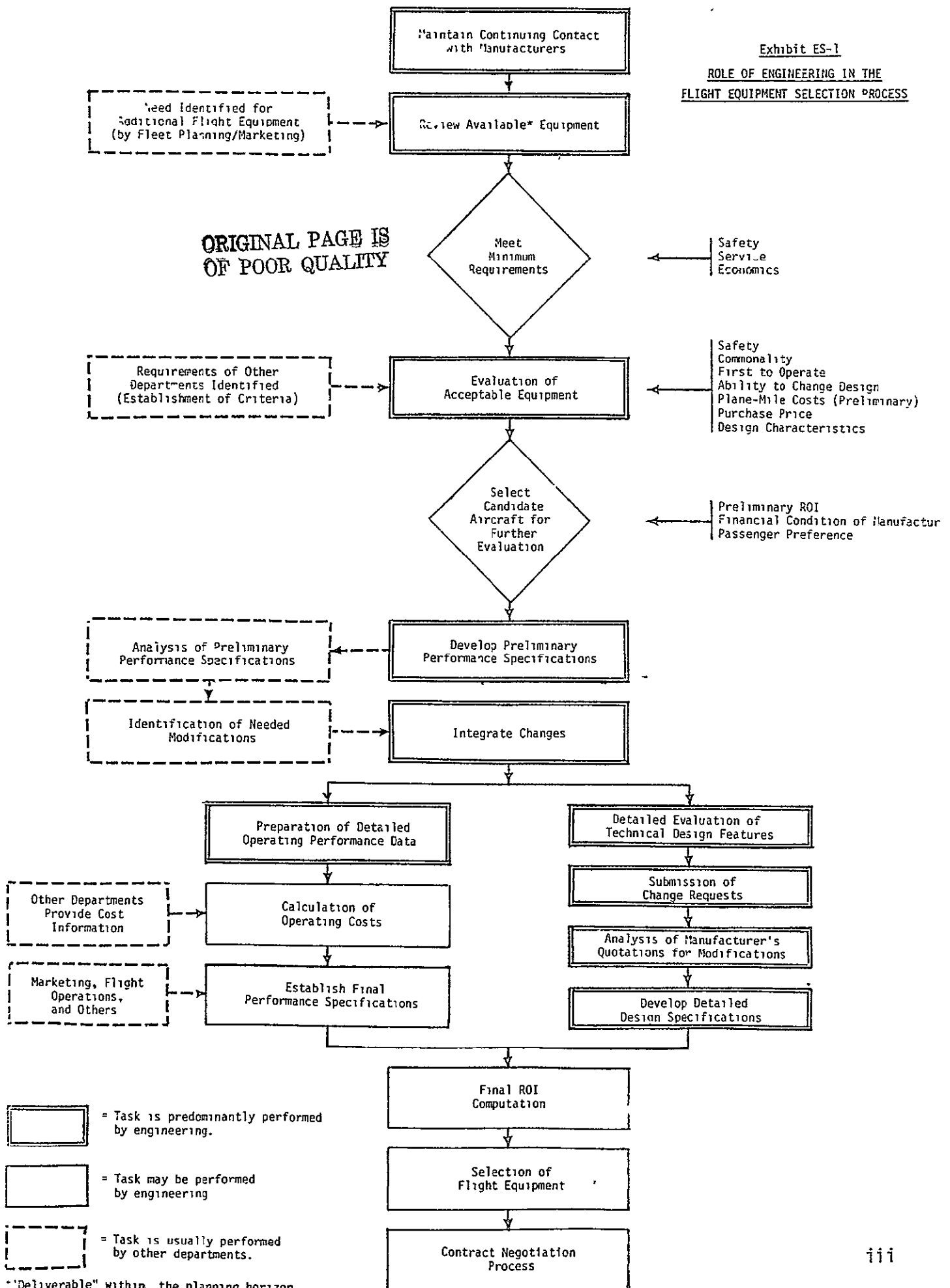
EXECUTIVE SUMMARY

The purpose of this study is to examine the role of the airline engineering department in the flight equipment acquisition process. The data for the study was collected from six airlines. The principal findings of the study include:

- The main conclusion of this study is that engineering activities permeate, but do not dominate the airline flight equipment decision process. That is, the products of engineering activities are necessary but not sufficient to complete the decision process. In addition, the role of the engineering department in the flight equipment decision process varies in each airline. However, the technical tasks required of engineering departments are consistent. Further, while the engineering department is actively involved in the flight equipment acquisition process, it is not usually involved with the acquisition decision.
- The principal criterion for the flight equipment acquisition decision is return on investment. However, when different aircraft are virtual substitutes for each other in terms of operations, marketing, and finance, then the importance of ROI as the decision criterion is diminished. Therefore, the importance of engineering criteria in the decision increases.

- ° There are two generic types of engineering activities which influence the flight equipment decision process: monitoring and evaluation. The monitoring activities include the acquisition and exchange of information which allows an airline's engineering department to maintain awareness of state-of-the-art technology. In addition, monitoring activities provide a means for the airlines to inform equipment manufacturers of future airline need. The evaluation process is the series of activities which the engineering department conducts in support of the airline flight equipment acquisition process. The process is graphically illustrated in Exhibit ES-1.
- ° The principal sources of information for the airline engineering departments in the monitoring process are the manufacturers of equipment. Subsidiary information sources include NASA publications and conferences, among others.
- ° The engineering department is the principal communication channel for technical information between:
 - the airline and equipment manufacturers,
 - the airline and government agencies,
 - the airline and other airlines,
 - the airline and technology-oriented trade associations.

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The engineering department's communication channel function occurs in both the monitoring and evaluation processes. The engineering department is proactive, i.e., initiating contacts and communication during the monitoring process. However, the engineering department is reactive to the needs of other departments during the flight equipment decision process.

- ° The level of risk associated with an equipment acquisition determines whether formal or informal analyses will be conducted by the engineering department.
- ° The principal factors influencing the diffusion of new technology via the engineering department for both components and systems are:
 - technical risk,
 - economic risk,
 - capital cost,
 - maintenance cost,
 - life cycle costing.

In addition, an important consideration in the acquisition of component technology is fleet commonality.

1. INTRODUCTION

The air transport industry has experienced rapid growth since the end of World War II. The character of the industry has changed from that of an infant requiring protection to that of a mature, self-sustaining segment of the transportation system. The shift from infant to mature industry has been characterized by growth in the size of airlines, increased capital intensity, and the adoption of a complex technology. In addition, industry growth has necessitated modification of airline organizational structure. That is, bureaucracy has been substituted for the small corporation or single proprietor structures prevalent during the early history of the airlines. The change in firm structure has altered the nature of management from that of a "seat-of-the-pants" entrepreneurship to one dependent upon the broad spectrum of activities titled "management science." Further, organizational change has altered the communication and decisionmaking processes within the firm.

The realignment of organization and management structure has changed airline decisionmaking information needs. The information required must be accurate, precise, and designed to reduce the risk in an investment decision. While the sources of information have expanded beyond those concerning technology, knowledge of the operating and cost characteristics remains central to the decisionmaking process. Yet, the technical evaluation process has not remained static. It has been subject to change since

aircraft technology has shifted from essentially simple mechanical machinery to complex electro-mechanical systems. The knowledge required to evaluate properly a complex system has fostered specialization in engineering analysis.

The development of complex aircraft systems has also altered the concept of innovation as applied to the aviation industry. The opportunities for innovation have multiplied due to the increased number of components required in an aircraft system. Thus, the adoption of innovations no longer addresses only the whole aircraft, but individual components as well. In addition, the escalating prices for new technology coupled with other economic factors have increased airline resistance to the procurement of unproven technologies. Sundry economic factors such as the price and supply of fuel have also encouraged the adoption of new technology components for existing systems.

The development of new technologies is both capital intensive and time consuming. In recent years the Federal Government has become the primary patron of basic research. In aviation, the National Aeronautics and Space Administration's (NASA's) mandate has included research and the application of technology to improve the safety and efficiency of aircraft. The efforts undertaken by NASA to fulfill this mandate have produced substantial knowledge and technology which can be applied in the design and manufacture of aircraft. While NASA technology has been disseminated, it is in the interest of both the public and industry to enhance the

diffusion of NASA developed or sponsored knowledge and technology. However, enhancing the transfer of NASA technology requires an understanding of the equipment acquisition process.

The latter has been the subject of recent research sponsored by NASA.¹ The results of that earlier research suggest:

With the flight equipment investment decision becoming more formalized and sophisticated, the engineering₂ evaluation process takes on increasing importance.²

The study recommended that NASA:

Take appropriate steps to acquire greater knowledge and understanding of the way in which airline engineering evaluations are₃ made in support of aircraft investment decisions.³

The current project is based upon the preceding recommendations and conclusions. The purpose of this project is to examine the role of airline engineering departments in the flight equipment decision process.

¹Gellman Research Associates, Inc., Analysis of Flight Equipment Purchasing Practices of Representative Air Carriers, prepared for National Aeronautics and Space Administration, Aircraft Efficiency Program (Washington, D.C., January 1977).

²Ibid., p. 5.

³Ibid., p. 63.

2. METHODOLOGY

The project was designed to be exploratory. The principal objective was to provide sufficient insight into the role of airline engineering departments in the flight equipment acquisition process to allow:

- ° the development of a descriptive model of the engineering function,
- ° determination of the relationship of the engineering department to other elements in the equipment acquisition process,
- ° identification of the relationship between the airline engineering department and the aircraft manufacturers,
- ° examination of the role of NASA technology/information in the airline engineering evaluation function,
- ° identification of barriers in the engineering function to the diffusion of new technology,
- ° development of a series of hypotheses designed to enhance the diffusion of new technology to the airlines.

The data were acquired through a series of interviews with representatives of six airlines. The airlines considered for inclusion in this study had participated in an earlier study entitled, "Analysis of Flight Equipment Purchasing Practices of Representative Air Carriers." The airlines included in the study were selected using the following criteria:

- the organizations had or have the ability to sponsor new aircraft,
- the organization is generally acknowledged to be at the forefront of technological knowledge with respect to aircraft, and
- the sample is representative of all the airlines meeting the preceding criteria.

Prior research efforts identified those individuals in each airline responsible for technical evaluation. These individuals were contacted and interviews scheduled. The subjects of the interview included the individuals who had the authority or responsibility to "sign off" on the technical evaluation. In addition, the project team interviewed other individuals on the engineering staff. A total of ten people were interviewed for this project.

The data-gathering instrument employed in this study was a structured interview protocol. Each question was designed to facilitate open-ended discussion. The instrument was designed to collect information in the six areas identified above. The protocol is composed of three sections.

The first section considers the tasks and activities required to maintain an adequate level of current awareness in flight equipment. The second section of the instrument is designed to identify and define the role of engineering in specific equipment investment decisions. Section three of the protocol asks the

respondent to discuss the evaluation process for one or more specific technologies. A copy of the instrument is included as the Appendix.

Prior to the interview, each airline received a copy of the instrument. The data was collected during personal or telephone interviews. Only one of the interview sessions was recorded. Extensive notes were taken during each of the remaining interview sessions. A detailed summary of each interview session was prepared.

The interview summary and notations on the interview protocol were reviewed by the project team. A model of the engineering evaluation process was prepared for each airline. In addition, the relationship of the engineering process to the equipment acquisition process was identified. Further, the role of the engineering department with respect to the manufacturer during both acquisition and non-acquisition periods was delineated.

The material obtained from the interviews and the analysis of each airline was evaluated by the project team. The object of the evaluation was to synthesize information about the individual airlines, and to:

- develop a "general model of the engineering function" in the flight equipment acquisition process,
- provide a "generalized" view of the relationship of the airline engineering departments with the manufacturer,

- develop a general list of engineering department barriers to the diffusion of new technology,
- identify the role of NASA and the airline engineering departments.

3. THE ROLE OF ENGINEERING AT EACH AIR CARRIER¹

This section describes the role of each airline engineering department in the investment decision process. The scope of activities assigned by each carrier to the engineering department varies. However, the variables considered in a technical evaluation are universal to all the engineering departments.

Carrier A

Carrier A, a large trunk airline, historically has been a first buyer of new aircraft. The responsibility for the technical evaluation of new flight equipment has traditionally rested with the technical development department. The technical development department is a semiautonomous unit of the engineering department.²

Financial problems have impeded the ability of Carrier A to acquire flight equipment. The activities of the technical development department have been substantially reduced as a result. In addition, the staff of the technical development department has been reduced to a skeleton force.

¹The letters identifying each carrier in this section correspond to those used in GRA's earlier report, "Analysis of Flight Equipment Purchasing Practices of Representative Air Carriers."

²The main part of the engineering department has the responsibilities of maintenance and technical management for the existing fleet. It should be noted that the Director of Technical Development at Carrier A has a greater impact on investment decisions than his counterparts at other airlines due to his experience and the regard for him which is held by upper level management.

The technical development department is responsible for monitoring advances in aircraft technology. The monitoring function is a customary activity of the department. It continues independent of equipment acquisition. The monitoring function is designed to collect nutritional information, i.e., knowledge which will be of use in the future. As such, the objective of the monitoring function is to obtain information which will be employed in the flight equipment acquisition process when the carrier's financial problems are resolved.

The monitoring function includes gathering information from both formal and informal sources. The primary sources of information are the airframe manufacturers. The Director of Technical Development conducts an annual visit to the aircraft manufacturers to review technological and conceptual advances. In addition, the technical director discusses the future needs of the airline with each manufacturer. The information obtained during the technical director's visits to manufacturers is summarized and disseminated to other departments.

Information is also gathered from government and various industry associations. The most useful sources of government information include: FAA publications, NASA publications, and NASA conferences. Industry association information is gathered from committees and publications of such groups as the Aerospace Industries Association of America (AIA) and the Air Transport Association of America (ATA).

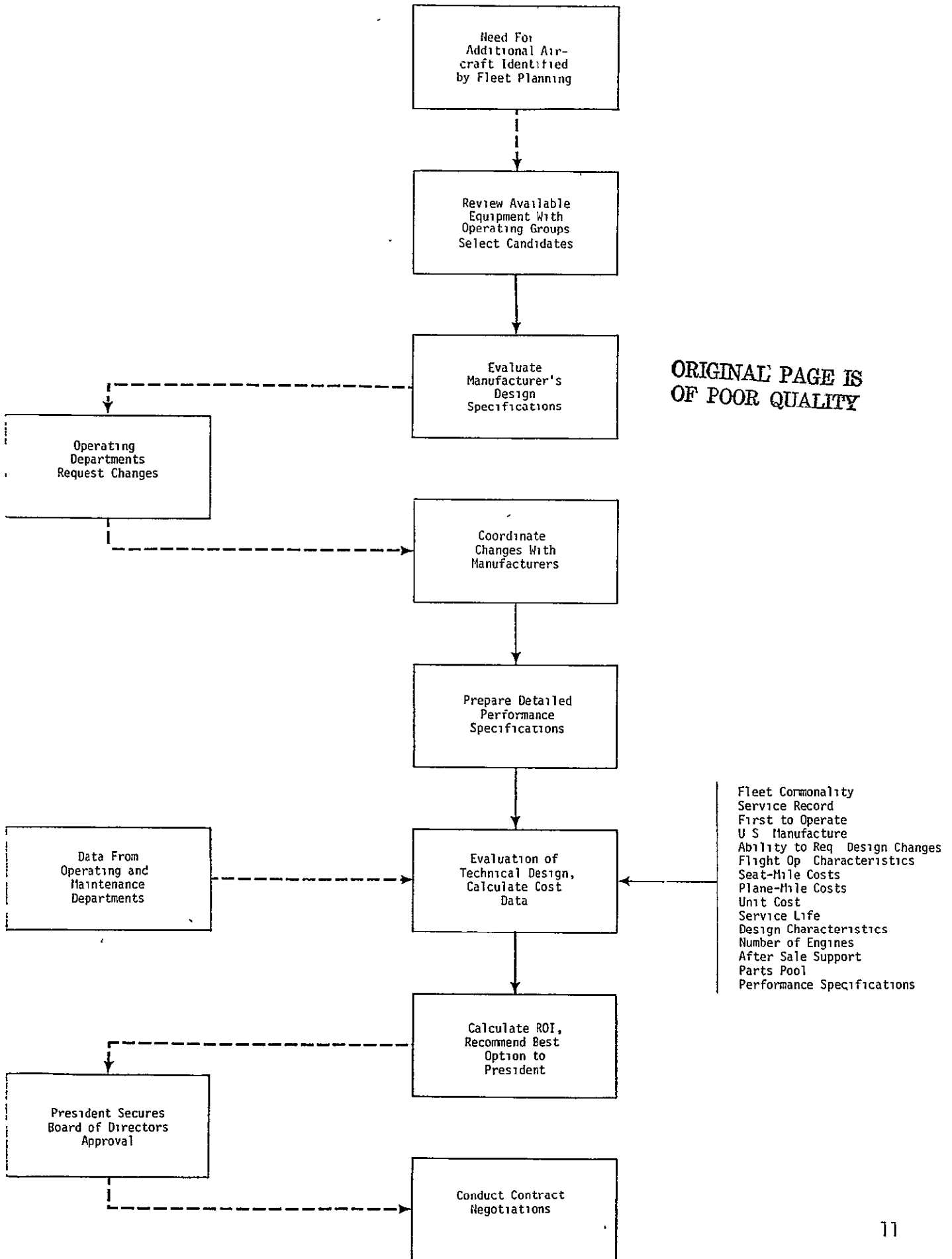
A descriptive model of the technical development department's role in the investment decision process is shown in Exhibit 3-1. The need for additional aircraft is identified in the fleet planning section of the marketing department. The next event is the formation of a team including representatives from technical development, marketing, finance, and flight operations. The team's functions include identifying candidate aircraft which meet the airline's needs and performing the investment evaluation of each aircraft.

Technical development's first task is to evaluate the manufacturer's design specifications. It then coordinates the development of detailed aircraft specifications with engineering, marketing, flight operations, and ground operations. The technical specifications of any required changes to the manufacturer's basic aircraft are prepared by the technical development group. The group is also responsible for obtaining equipment prices from the manufacturer. When this process is complete, technical development prepares final performance specifications for the aircraft. A technical evaluation of the aircraft is then performed.

The information used in evaluating a particular aircraft model comes primarily from the manufacturer, because at this phase of the acquisition process, knowledge of detailed specifications is required to develop cost information. The airlines' maintenance and operating departments provide data to support the engineering analysis. Direct operating costs and life-cycle costs are

CARRIER A

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calculated using airline cost factors consistent with the aircraft performance specifications. The technical development department then computes the capital cost of the equipment³ and the return on investment (ROI).

The technical development department prepares a recommendation of the best aircraft option. The recommendation is submitted to the airline president. If approval is granted to acquire the aircraft, the technical development department conducts contract negotiations with the manufacturer. In addition, the department is responsible for monitoring the production of the aircraft.

The major criterion used for the aircraft purchase decision is ROI. However, when competing aircraft designs are similar with respect to range and capacity (e.g., L-1011 and DC-10), other factors influence the evaluation process. Under this circumstance, differences in component technologies, e.g., airframe design, safety features, etc. have increased importance. These features often cannot be considered using ROI. Thus, subjective information about these factors is included in the engineering department recommendations.

Carrier C

Carrier C, a major trunk airline, has been a traditional sponsor of new aircraft. In addition, this carrier is recognized

³These include expenditures for the airframe, spares, support material, provisions, crew training, ground equipment, simulators, towing equipment, etc.

as a leader in defining the airline industry's aircraft needs. The need for new aircraft is identified by the fleet planning group. In addition, fleet planning selects candidate aircraft for evaluation. However, fleet planning relies on information provided by the engineering staff to make these decisions.

The engineering staff has two distinct roles in the evaluation of new flight equipment. The first is to monitor the state-of-the-art in aircraft technology. The second is to perform the detailed analysis required in the technical evaluation of candidate aircraft.

The monitoring function is incorporated in the job description for engineers. The staff at this carrier uses numerous information sources to monitor the state-of-the-art in technology. These information sources include: trade magazines, manufacturers' visits, manufacturers' publications, professional journals, industry association meetings and publications, as well as NASA technical research studies and meetings. This carrier also performs technical studies for both NASA and the military. In addition, some of its personnel serve on industry committees which examine new technology.

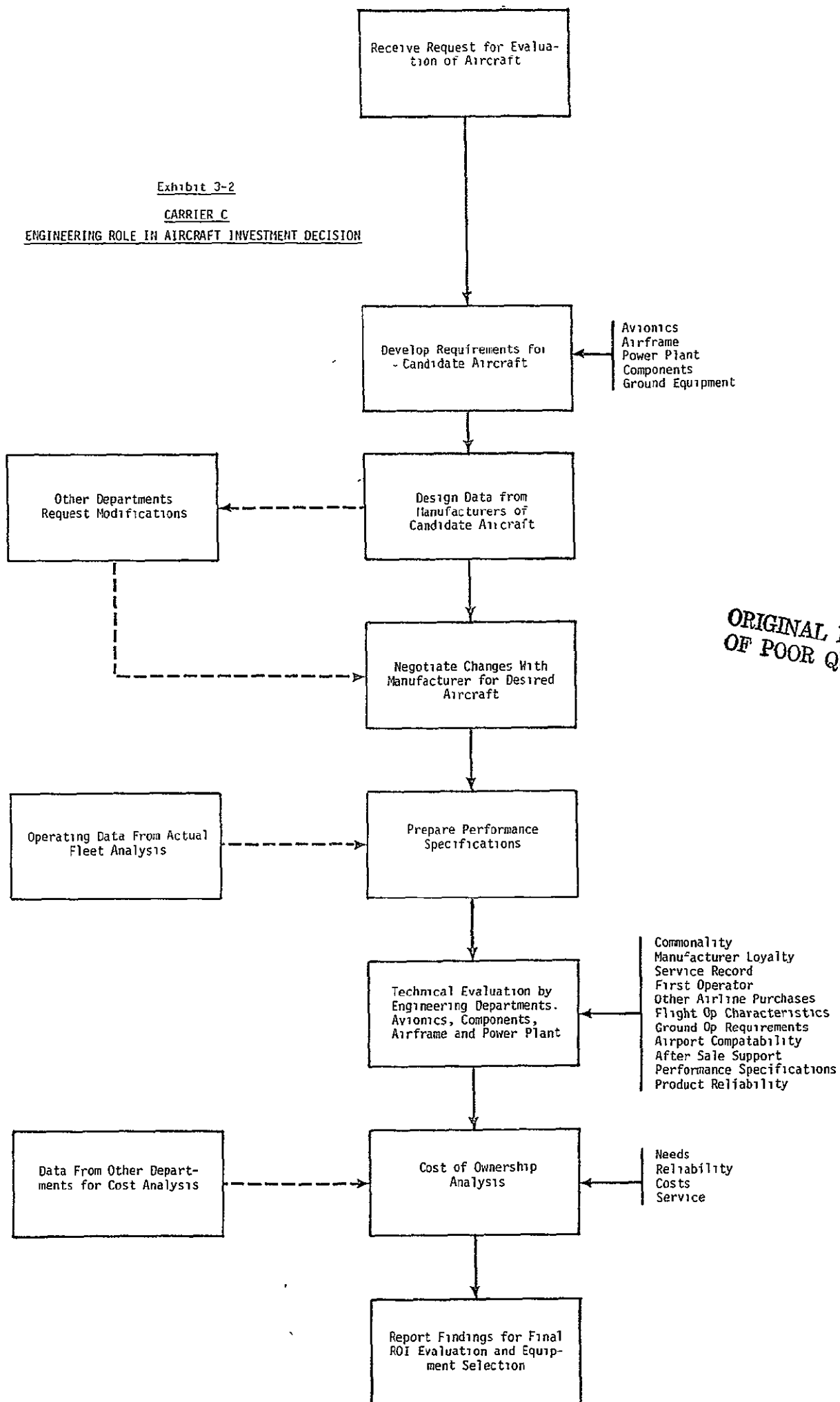
The detailed technical data used to evaluate a candidate aircraft are obtained from the manufacturer, other airlines, and internal company sources. These sources can provide data in enough detail to generate cost estimates usable in the calculation of ROI.

A descriptive model of the role of Carrier C's engineering department in the investment decision process is illustrated in Exhibit 3-2. A request by fleet planning to the Vice President of Maintenance and Engineering initiates the technical analysis. Requirements are developed in conjunction with operating and marketing departments for the candidate aircraft. Next, various engineering groups (avionics, airframes, powerplants, components, and ground equipment) use manufacturer's data to prepare preliminary specifications. These specifications are forwarded to the operating departments for evaluation. The engineering department incorporates requests for changes in the detailed performance specifications.

Actual airline data (including route structure, range, and payload) are used to construct a scenario for the aircraft evaluation. The scenario and performance specifications provide the engineering groups with the information to evaluate the candidate aircraft. On the basis of this analysis, engineering will gather data from the operating departments to perform a cost-of-ownership analysis. This analysis considers the airline's new equipment objectives, the aircraft's reliability, the manufacturer's service support, and the operating and maintenance costs of the aircraft.

Results of the cost-of-ownership analysis are reported to a team comprised of representatives from operations, marketing, and engineering. The team determines whether the aircraft meets

Exhibit 3-2
 CARRIER C
 ENGINEERING ROLE IN AIRCRAFT INVESTMENT DECISION



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return-on-investment criteria, as well as government standards for safety, noise, and air pollution. The team recommends the purchase of a specific aircraft model. The engineering department's formal role in the aircraft evaluation process is complete. However, the president may request additional technical information before presenting the purchase proposal to the board of directors for approval.

Carrier C's engineering staff believes it is becoming more sophisticated. Models to establish cost and performance data have been developed to enable critical assessment of manufacturer claims. In addition, a fuel-consumption model has been developed because the manufacturer's data did not coincide with this carrier's experience. Furthermore, when the manufacturer's data is used, the staff carefully examines the underlying assumptions.

Carrier D

Carrier D, a major trunk airline, normally is a follow-on buyer of new aircraft. However, occasionally the carrier has been a sponsor of new aircraft types. The technical evaluation of new aircraft is conducted by a special unit in the engineering department.

This carrier's financial performance has been poor in recent years. The carrier's emphasis on short-term profitability and the difficulties encountered in obtaining financing have sometimes dominated the flight equipment investment decision. The staff at

this carrier view the financial constraints as temporary. When the carrier's financial condition improves, ROI will be reinstated as the primary acquisition criterion.

To keep current with developments in the aircraft industry, information is gathered from many sources. All engineers, regardless of assignment, are required to maintain proficiency in their field. Their primary sources of information include: manufacturers' briefings and visits; industry committees and publications; and NASA committees, seminars, and publications. The NASA information is more useful to this carrier in evaluating potential applications of future technologies than in evaluating specific flight equipment.

The weak financial condition of the carrier precludes it from extensive monitoring. Therefore, only the most promising near-term technologies receive a thorough analysis. When a formal analysis is performed, a report is forwarded to other parties and departments in the company.

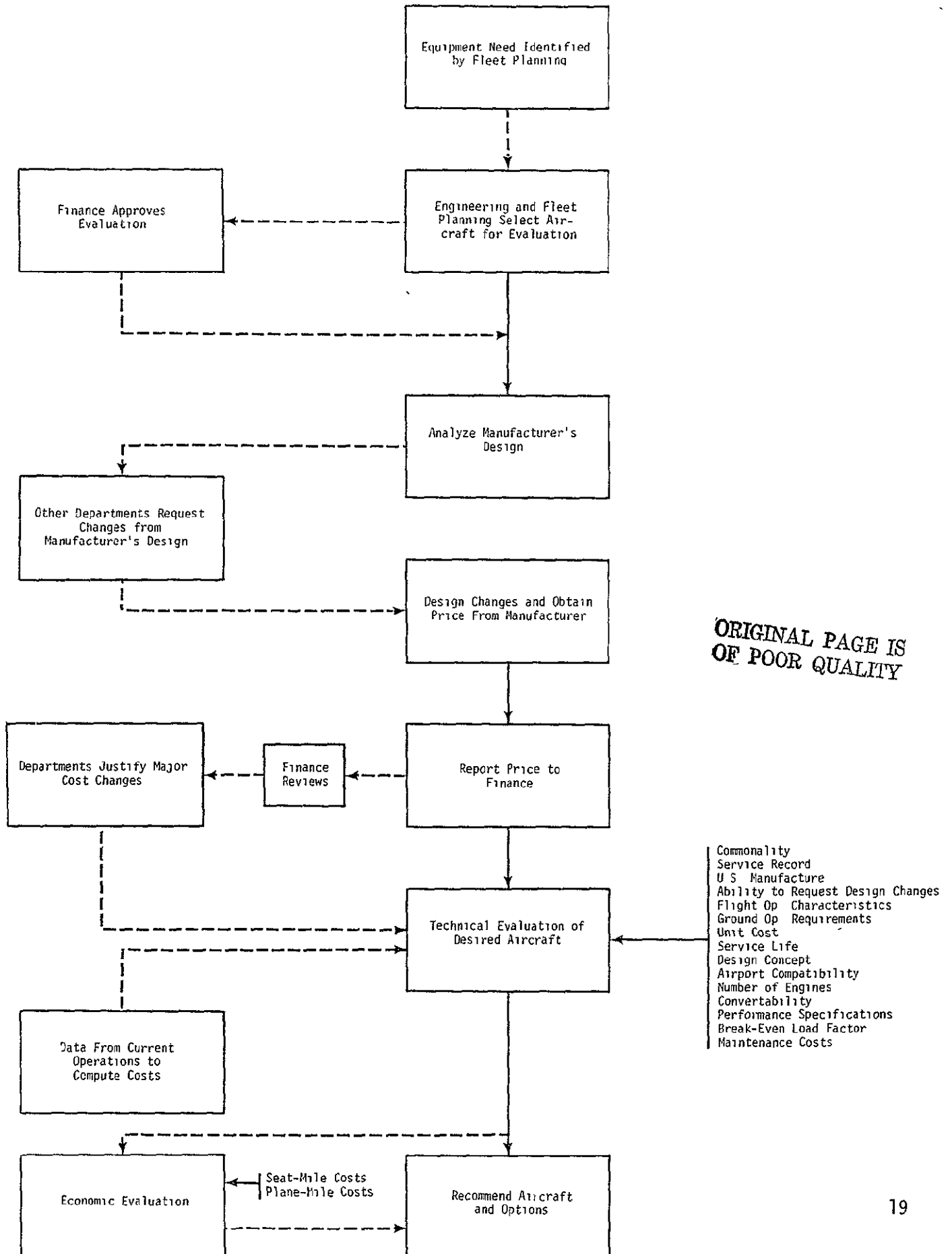
The present short-range outlook of this carrier dictates that the greatest consideration be given to those investment possibilities which can significantly decrease operating costs (e.g., reduce fuel consumption). Commonality across the fleet is also important because it produces savings in maintenance and spares requirements. Increased passenger appeal is an important consideration because it can be expected to increase revenue.

A descriptive model of engineering's role in the aircraft acquisition process is shown in Exhibit 3-3. In the first step, the fleet planner identifies the need for additional equipment and, along with the engineer responsible for new aircraft evaluation, selects the specific candidate aircraft to be evaluated. Finance, if it determines funds may be available, authorizes the evaluation process to continue.

Engineering evaluates the design specifications of the manufacturer's candidate aircraft. The engineer in charge of the evaluation coordinates the activities of various operating departments (flight operations, in-flight services, maintenance, and ground services). The intent of the departments' activities is to determine whether modifications are necessary in the standard design of the aircraft. If so, the engineering department performs a technical analysis of these changes. In addition, the manufacturer is asked to revise the price quotations. Each technical change is evaluated to determine the tradeoff between the impact on purchase price (usually an increase) and operating costs (usually a decrease). This procedure compels the department requesting the technical change to justify the need for each modification.⁴

⁴Such justification is especially important for modifications which are complex and/or specifically tailored to this carrier. Such modifications are least likely to be ordered by other airlines; and therefore, their entire development cost must be spread over the few units ordered by Carrier D, which makes them relatively expensive.

CARRIER D
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The finance department evaluates the equipment prices. It then determines if financing can be arranged. The department approves the procurement, then a full technical evaluation is performed by the engineering department.

To assist in the technical evaluation, the company has developed a model to project operating costs for various routes. Data is developed for each month of the year, to reflect the carrier's seasonal traffic loads. The cost data are applied to the candidate aircraft's performance specifications to estimate route-specific operating costs.

At this carrier, engineering analysis is the major internal function in the investment decision process. Technical specifications and projected costs are used to perform the economic evaluation. When this evaluation is complete, engineering recommends a specific aircraft for purchase. Finance also presents its report on the availability of credit when the engineering department recommendations are presented. The results of the analysis are forwarded to the airline president. He presents the recommendations to the board of directors for approval.

Carrier E

Carrier E, a trunk airline, operates one of the largest fleets in the industry. This carrier is a traditional first operator of new aircraft. It is an acknowledged spokesman in defining airline needs. This carrier uses ROI as the principal criterion for equipment selection decisions.

The engineering department is part of this carrier's maintenance department. The engineering department's role in the equipment decision process is to develop information on aircraft characteristics for use by other departments in their economic evaluations.

In prior years, the engineering analysis was often the only thorough assessment performed during the investment decision. Each new generation of aircraft incorporated substantial improvements in performance (i.e., speed, range, and payload). Thus, the prime task in the equipment acquisition process was the assessment of performance claims.

In recent years, cost reduction (not improved performance) has been the incentive for acquiring new aircraft. Thus, the comparison of lower operating costs to performance has increased in importance. Engineering provides a substantial amount of the information used in such economic analysis. However, the engineering department's role as sole evaluator of candidate aircraft has ceased.

As with other carriers, members of the engineering staff monitor a variety of information sources to maintain their awareness of new technologies. Technologies which are not embodied in a product are monitored through professional literature, including NASA publications. In fact, members of the engineering staff at this airline serve on NASA and various industry committees concerned with new technology. They also have consulted for NASA on various technology assessments.

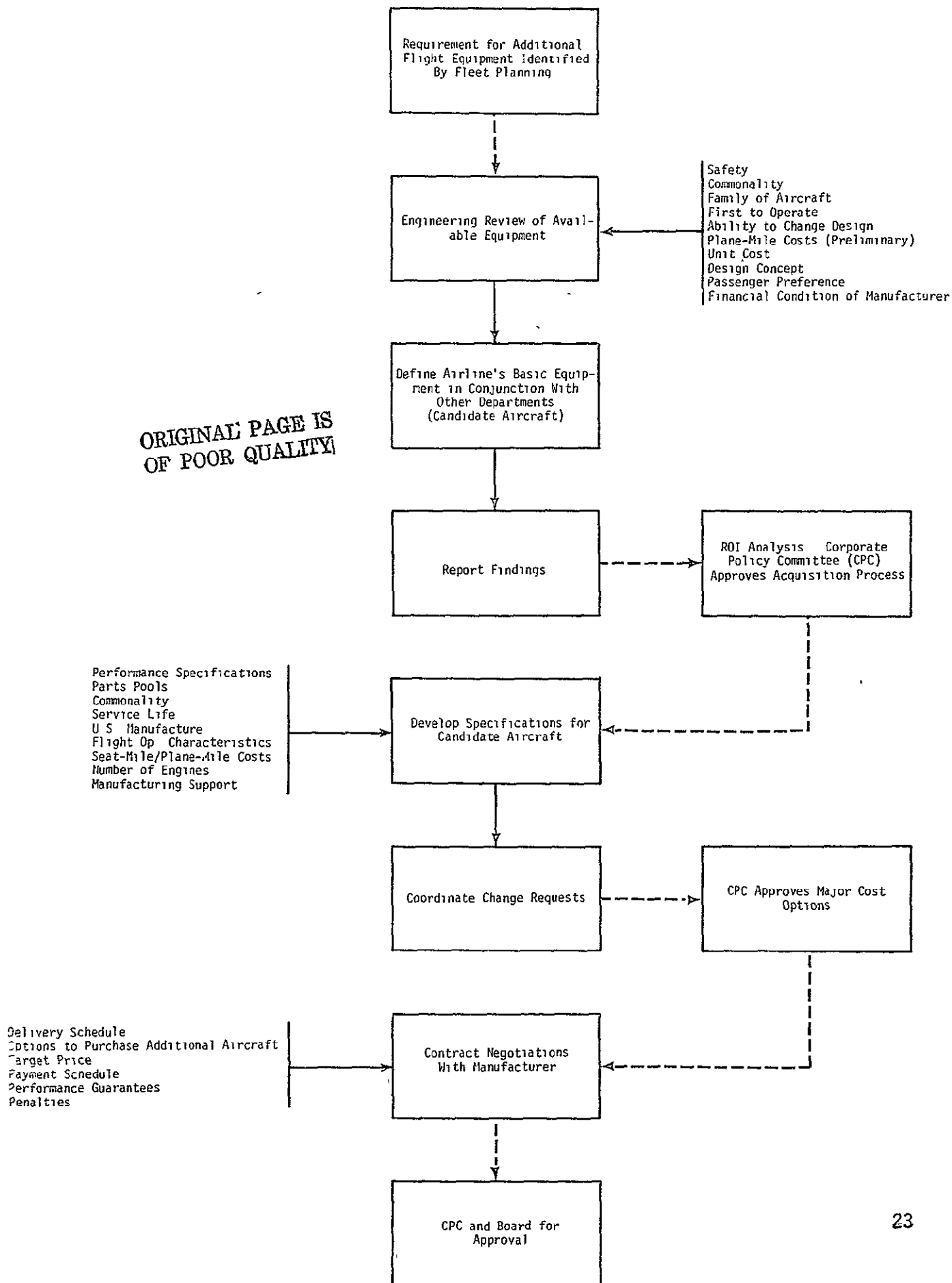
Monitoring is performed for two general purposes. First, it "educates" the engineering staff so that it will be capable of evaluating new technologies that reach the market. Second, engineering can pass relevant information on to fleet planning and other departments for use in long-range planning.

A descriptive model of the engineering role in the investment decision process is shown in Exhibit 3-4. The flight equipment evaluation process is initiated by fleet planning which identifies a need for additional aircraft. Engineering, with other airline departments (operations, marketing, and fleet planning), defines a "basic" airplane for the company. The aircraft must meet the airline's minimum safety, service, and economic standards to warrant further consideration. At this stage, the Corporate Policy Committee (CPC) must approve continuation of the aircraft acquisition process.

Engineering, flight operations, and marketing each delegate two representatives to a specifications team. This team is responsible for developing any changes required in the candidate aircraft. Engineering designs these changes and obtains revised prices from the manufacturer. When engineering has completed the technical evaluation phase, the specification team forwards a report to the CPC. The CPC must approve any major cost options and authorize contract negotiation.

Engineering participates on the contract negotiation team. This team reports the results of negotiations with the manufacturer to the CPC. The CPC presents the negotiated contract,

CARRIER E
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and the information gathered earlier, to the board of directors for approval.

This carrier's highly structured, economics-oriented investment decision process may indicate the future role of engineering in other airlines. In this carrier's system, engineering performs the technical evaluation of new equipment and provides a substantial amount of the operating data used in the economic evaluation. The engineering department projects operating and maintenance cost parameters for new aircraft. These are incorporated into cost estimates used in the company's discounted cash flow analysis.

In addition, this carrier is concerned with the "life-cycle costs" of new technology aircraft. Thus, the engineering department's skills are critical in the evaluation of new technology.

Carrier F

Carrier F is a medium-size trunk carrier with a consistently good financial record and a reputation for strict cost controls. It also has been a first buyer of new model aircraft.

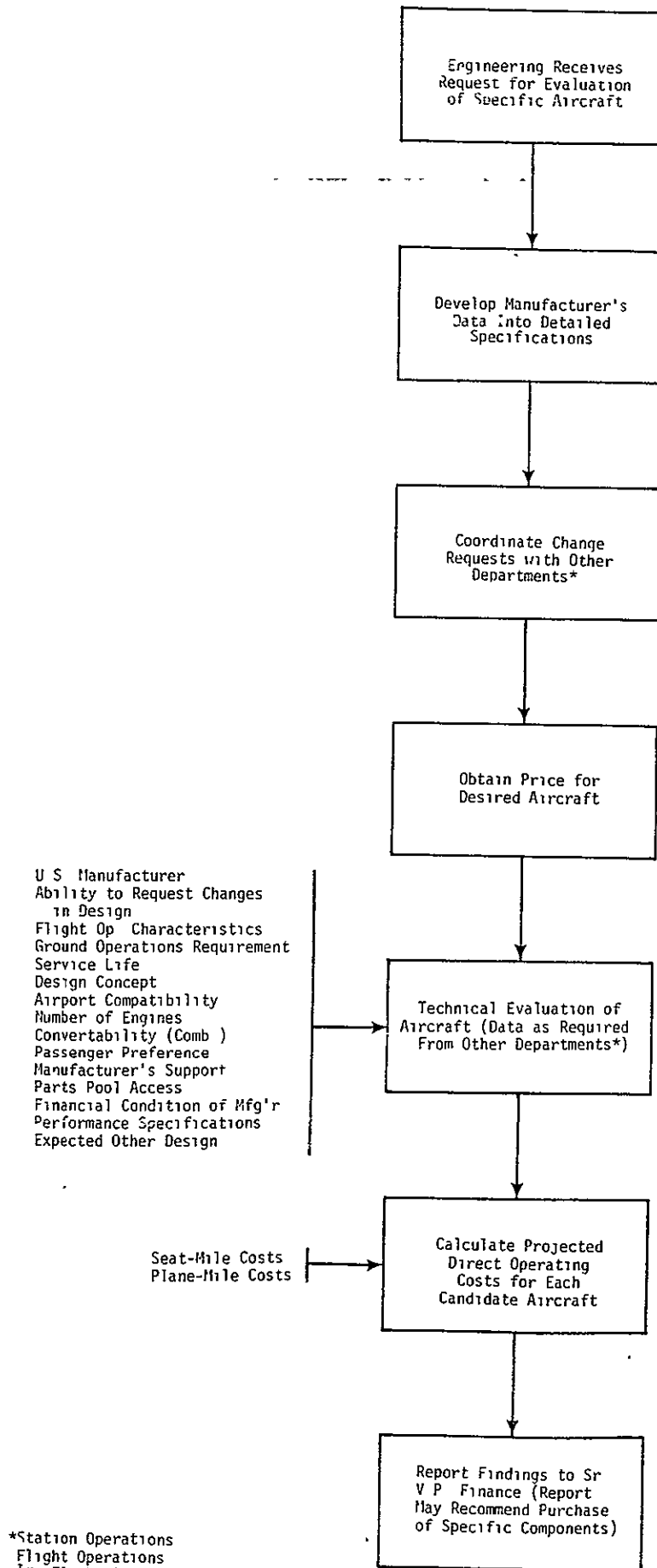
At this carrier, the fleet-planning group (two persons) conducts an ongoing analysis of possible additions to the fleet. In doing so, it maintains informal communication with the president and the technical operations department. Once fleet planning has identified candidates and the company president has given authorization to proceed, engineering performs a technical evaluation of these aircraft. The engineering department is under the general direction of the Vice President of Technical Operations.

The engineering group at Carrier F keeps informed of developments in new technologies through periodic briefings from equipment manufacturers, review of trade magazines, attendance at seminars, and participation on ATA and NASA committees. Information concerning relevant technology is summarized and disseminated through the office of the Assistant Vice President of Engineering. Although the technologies that may be investigated are not restricted, efforts are concentrated on equipment which will reduce direct operating costs.

Responsibility for the technical evaluation of new aircraft is specified in the job description for certain engineering staff members. When a need for a specific evaluation arises, a performance engineer is assigned to coordinate the analysis. This individual is responsible for gathering all data, ensuring that the cost analysis is performed, and submitting a report on the evaluation.

A descriptive model of the engineering role in the investment decision process of Carrier F is shown in Exhibit 3-5. Engineering becomes involved in the investment decision when it receives a request to evaluate a specific aircraft type(s). At this point, a performance engineer is assigned to coordinate the analysis. Engineering develops detailed specifications based on the manufacturer's design. The data submitted by the manufacturer are carefully examined, as are the methods and assumptions that the manufacturer used in the preparation of the data. Data obtained from actual tests are considered more credible than manufacturer's estimates.

ENGINEERING ROLE IN AIRCRAFT INVESTMENT DECISION



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*Station Operations
Flight Operations
In-Flight Services
Finance
Marketing

Engineering's next step is to collect and evaluate requests for design alterations submitted by the operating departments. The engineering department prepares a formal request for change, which is submitted to the manufacturer. The manufacturer quotes a price for each modification.

An evaluation of the aircraft is then performed by the engineering department. Engineering obtains the necessary data from other airline departments (station operations, flight operations, in-flight services, finance, and marketing) to project direct operating costs.

The engineering department forwards its calculations to the Senior Vice President of Finance who, in conjunction with the marketing department and the president, selects the aircraft. Engineering does not prepare the purchase recommendation. However, it does prepare a recommendation for which component technologies should be acquired with the aircraft. The president then recommends the purchase of a specific aircraft to the board of directors. The primary factor in the president's evaluation is ROI.

Carrier G

Carrier G is an all-cargo airline with both domestic and international routes. It is relatively small compared to the trunk carriers. This carrier has never sponsored a new aircraft model. This airline's equipment purchases have been either derivatives of existing designs, or used aircraft.

The technical analysis of new aircraft is conducted by the Director of Environmental Engineering. The environmental engineering group is part of the maintenance and engineering department.⁵ However, due to this carrier's small size, individuals may perform more than one function in the investment decision process.

This carrier does not have the resources to evaluate adequately the acquisition of innovative aircraft.⁵ If such an evaluation were required, the engineering staff would consult with other carriers to acquire the needed information. In addition, FAA certification of the new technology application would be an important factor in the evaluation.

The limited resources of Carrier G also inhibits the activities in the monitoring process. The engineers keep informed of new technological advances through trade magazines, manufacturer's reports, professional journals, and NASA reports and conferences. Four people have the responsibility for evaluating new technology and informing the rest of the company of their relevant findings. There are few formal constraints on which technologies the staff may evaluate. However, the staff is expected to focus its efforts on items which appear useful in the near future.

A descriptive model of engineering's role in the flight equipment investment decision process is shown in Exhibit 3-6.

⁵The current all-cargo fleet is composed of either aircraft developed for the military, or modified passenger airplanes. As such, they are not designed to optimize commercial freight operations. However, the staff indicated that the engineering evaluation would be of paramount importance if a dedicated commercial all-cargo aircraft were developed.

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graph TD
    A[Construct Fleet Plan] -.-> B[Chief Operating Officer Approves Evaluation]
    B -.-> C[Identify Candidate Aircraft]
    D[Manufacturers  
Government Aircraft Purchases  
Other Airline Purchases  
Used Aircraft Availability] --> C
    C --> E[Technical Evaluation of Candidate Aircraft]
    F[Input from Other Carriers on New Technology Equipment] -.-> E
    G[CRAF  
Performance Specifications  
Performance Flexibility  
Commonality  
Service Record  
Ton-Mile Costs  
Plane-Mile Costs  
Airport Compatibility  
Design Concept  
Number of Engines  
After Sale Support  
U S Manufacturers] --> E
    H[Data From Operating Departments to Project Costs] -.-> E
    I[Cargo Profitability Evaluation] -.-> E
    J[Marketing Evaluation] -.-> E
    E --> K[Design or Evaluate Cargo Modification]
    L[Data From Financial Analysis] -.-> M[Synthesize Results Identify Options to Chief Operating Officer]
    K --> M
    M --> N[Chief Operating Officer Approves Evaluation]
  
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The Director of Environmental Engineering (DEE) coordinates with marketing to identify the need for additional aircraft. The DEE then prepares the fleet plan. The chief operating officer must approve the evaluation of new aircraft.

If the evaluation is approved, a task force is formed with representatives from marketing, engineering, operations, and finance. Their first responsibility is the identification of candidate aircraft. Engineering then performs a technical evaluation of the candidate aircraft. When evaluating a specific aircraft, engineering gathers detailed information from manufacturers and other airlines where possible. Manufacturer's models are used to develop aircraft performance data. However, this carrier is skeptical of manufacturer's data due to past problems. Carrier G generally supplies the manufacturers with operating data for inclusion in models.⁶

Next, engineering reports the interim findings to the operations representative. The operations group then estimates the profitability and ROI of the airplane in cargo operations. Finance also determines if financing is available for the aircraft. The marketing representative evaluates the candidate aircraft in order to ensure that aircraft will satisfy the expected demands of shippers. The engineering department also evaluates or designs the cargo system.

⁶This carrier is currently developing its own models to simulate aircraft performance. These are viewed as being a step in the process of gathering accurate and detailed cost data, which is currently unavailable.

The principal product of the engineering analysis is a report containing detailed performance specifications and the cost figures. Other factors considered in the engineering analysis include: after-sale support of the manufacturer, the aircraft design concept, and the compatibility of the aircraft with cargo handling systems and airports. The engineering analysis is combined with reports from marketing and operations and sent to the finance department for analysis.

The comprehensive analysis is presented to the chief operating officer who evaluates the recommendations and selects the options to be presented to the board of directors. However, the chief executive of this carrier is a "seat-of-the-pants" entrepreneur. Thus the results of rigorous technical and financial analyses may be subordinated to the "business judgment" of the chief operating officer.

4. ANALYSIS

Functions of the Engineering Department

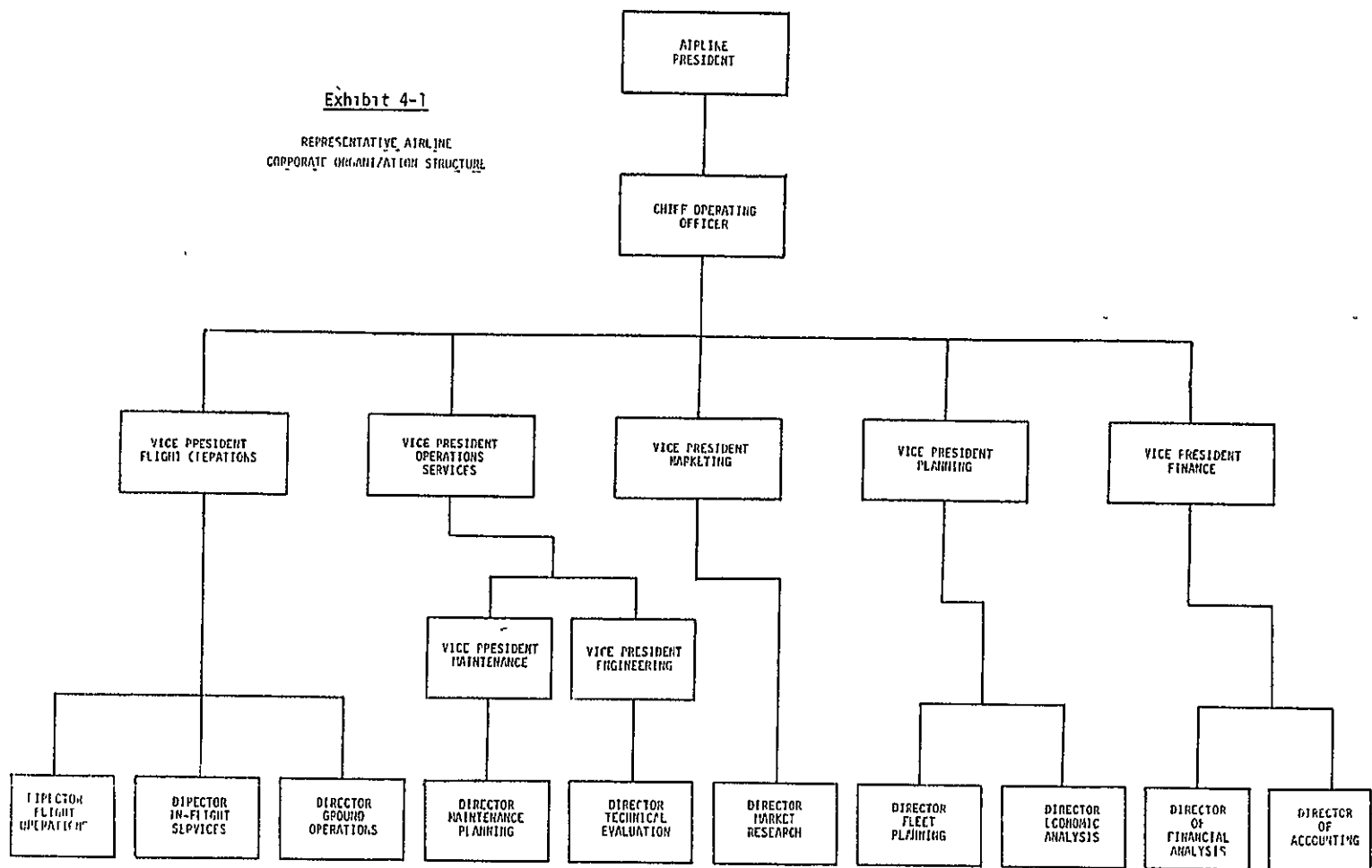
The engineering department is responsible for problem solving and technical evaluation related to flight equipment. The organization chart for a representative airline, Exhibit 4-1, indicates the location of the engineering department in the company. The diagram is only a schematic representation of the firm's structure. It identifies those organizational units which perform key functions in the equipment investment decision process.

The data collected during the interviews suggest that the engineering department performs three functions:

- 1) problem solving and monitoring activities in support of fleet operations;
- 2) information gathering and evaluation specific to the acquisition of new flight equipment (evaluation);
and
- 3) information gathering for monitoring developments in aviation technology (monitoring).

The first function is the principal activity of the engineering department. It is a continuous responsibility concentrating on the day-to-day operation of the airline. Examination of this function is beyond the scope of this report. The remaining functions are central to this study. Both of these functions are performed as part of the flight equipment decision process.

Exhibit 4-1
 REPRESENTATIVE AIRLINE
 CORPORATE ORGANIZATION STRUCTURE



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However, there is an important distinction between these activities. The evaluation function is part of a current equipment acquisition process; that is, the relevant activities are conducted to aid an immediate flight equipment acquisition decision. The monitoring function is concerned with future, rather than current, equipment acquisition. The activities and purposes of the monitoring and evaluation functions are described below.

The Monitoring Process

The purpose of the monitoring process is to identify and evaluate new or potential technologies which may be pertinent to the future flight equipment needs of the airlines. It should be noted the persons interviewed indicated that the extent of monitoring varies with the specific manufacturer involved. In this process the engineering department serves as the principal communication channel for technical information between:

- ° the airline and the equipment manufacturers,
- ° the airline and the relevant government agencies,
- ° the airline and technology-oriented trade associations,
- ° the airline and relevant professional or standard setting groups, and
- ° the airline and other airlines on technical matters.

Information is exchanged through both formal and informal mechanisms. Formal means include books, serials, data, and other

forms of recorded information. Informal means include the exchange of information through personal contacts including site visitations, telephone conversations, and oral presentations. The exchange of information through the monitoring process allows the engineering staff to:

- monitor the development of new technology,
- perform informal evaluations of the potential effect of new technology on the airline's operation,
- provide relevant information on new and future developments to other departments of the airline, and
- inform equipment manufacturers and other relevant parties of the future needs of the airline.

The primary sources of information used in the monitoring process include:

- Manufacturers (airframes, engines, avionics, subsystems);
- Professional societies (publications and meetings),
 - American Institute of Aeronautics and Astronautics,
 - Society of Automotive Engineers,
 - American Society of Civil Engineers;
- Industry trade associations (conferences and committees),
 - Aerospace Industries Association of America,
 - Air Transport Association of America,
 - International Civil Aviation Organization,
 - International Air Transport Association;




- International aerospace abstracts;
- Technical and trade publications;
- Research contracts;
- NASA,
 - Research and Advisory Council (committees, minutes),
 - STAR--Abstract Announcement Journal,
 - Formal Series Reports (technical memoranda, contract reports, special publications, reference publications, special reports),
 - Conferences and seminars,
 - Contracts for research or comments on research.

The relative importance of a number of information sources to the engineering department monitoring process is indicated in Exhibit 4-2. It is clear that the most important source of information for each of the airlines is the manufacturer. The data also suggest that the nationality of the manufacturer influences the intensity of communication. There is a clear preference for communication with domestic manufactures. This preference obtains because the domestic manufacturers have built over 90 percent of the aircraft in the U.S. fleet. The domestic manufacturers are viewed as the primary source of supply for aircraft. The interest of the airline can best be preserved through a continuing dialog with the primary suppliers. In addition, yearly site visits by U.S. airlines and domestic manufacturers to each other's facilities are customary. It is an important

Exhibit 4-2

IMPORTANCE OF EXTERNAL INFORMATION SOURCES
IN MONITORING PROCESS

SOURCE	AIRLINE					
	A	C	D	E	F	G
MANUFACTURERS	Most Important					
TRADE PRESS	Important	Important	Important	Important	Important	Important
NASA	Second Most Important	Second Most Important	Second Most Important	Second Most Important	Second Most Important	Important
FAA	Important	Important	Important	Important	Important	Most Important
INDUSTRY ASSOCIATIONS	Important	Important	Important	Important	Important	Important
PROFESSIONAL SOCIETIES	Important	Important	Important	Important	Important	Important
OTHER AIRLINES	Second Most Important	Second Most Important	Second Most Important	Important	Second Most Important	Most Important

	Most Important
	Second Most Important
	Important

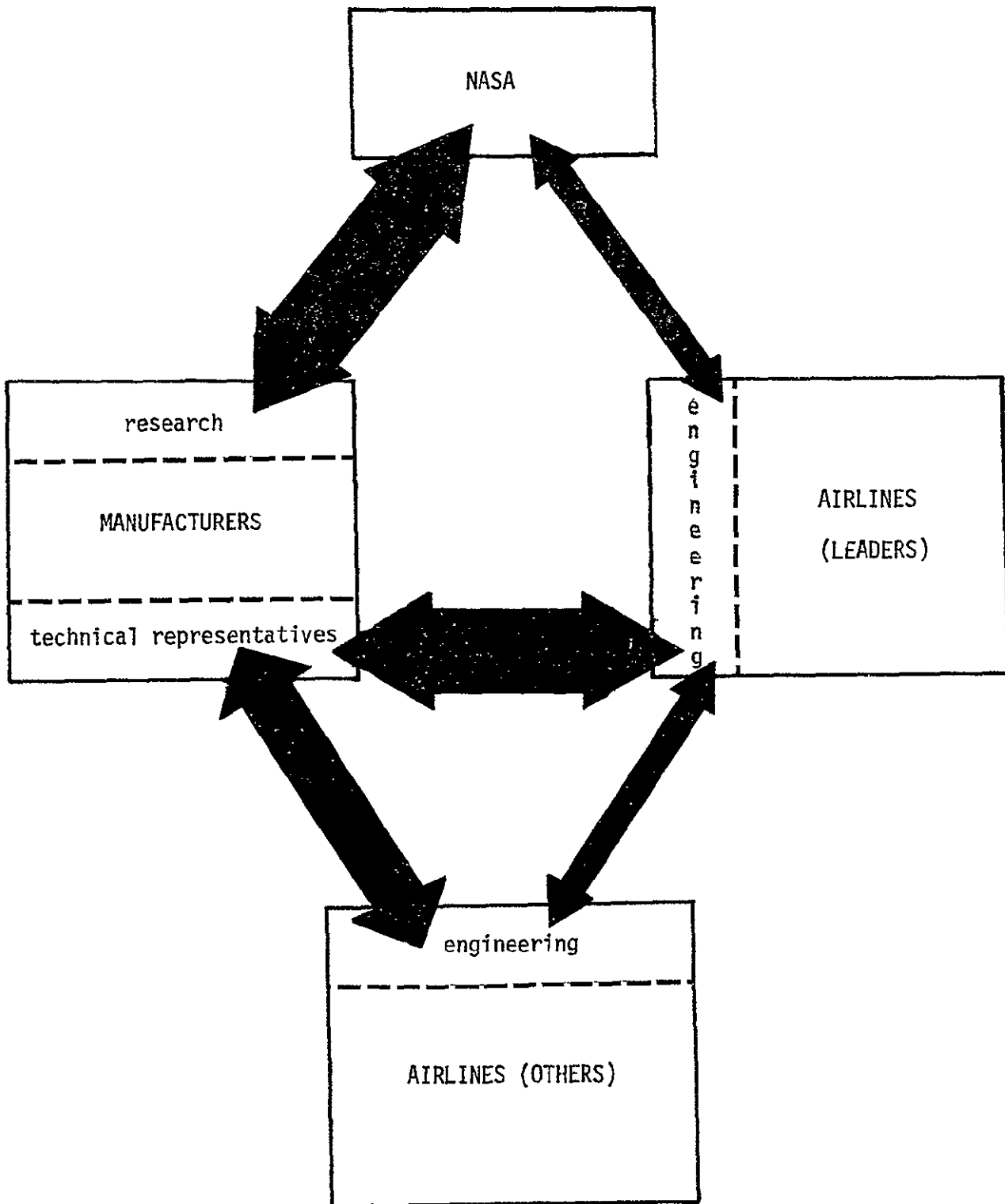
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mechanism in the monitoring process for information transfer. The use of site visits to exchange information with foreign manufacturers is limited. Foreign manufacturers periodically visit U.S. carriers, but airline staff do not regularly visit foreign producers. Of course, if the airline is evaluating a specific foreign technology, international site visits are conducted.

Information sources of secondary importance include: manufacturers, the trade press, NASA, FAA, industry associations, professional societies, and other airlines. The role of NASA in the monitoring process is vividly illustrated in the schematic diagram shown in Exhibit 4-3.

One of the purposes of the monitoring process is to inform the equipment manufacturers of the airlines' future needs. This exchange of information is designed to influence the early stages of the manufacturers' process of innovation. A descriptive model of the process of innovation for an equipment manufacturer is shown in Exhibit 4-4. The influence of the airline engineering department on the manufacturers' process of innovation is graphically illustrated. The definition of future airline needs is clearly intended to influence the R&D rather than the production function of the innovation process. It should be noted that the exchange of information between the airlines and manufacturers during the monitoring process is continuous. For instance, the engineering department may suggest a need; the manufacturer will identify a technological solution. Engineering comments on the

Exhibit 4-3



FLows OF INFORMATION FROM
NASA TO THE AIRLINES

Primary sphere of influence of the airline engineering monitoring process

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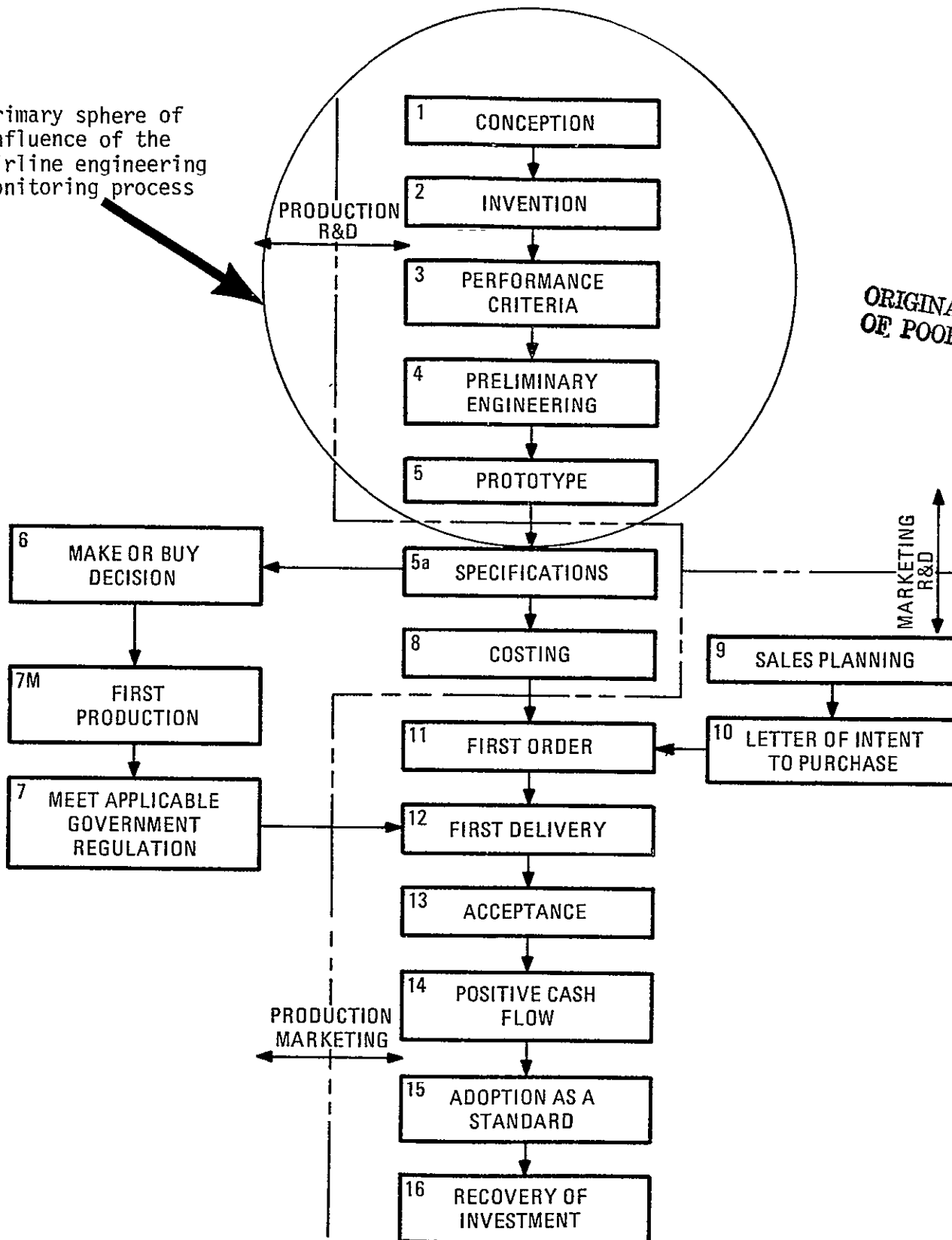


Exhibit 4-4

MANUFACTURERS' PROCESS OF INNOVATION

technological solution; the manufacturer modifies the technology. This exchange continues until both parties are satisfied. Therefore, the incorporation of future airline needs in the manufacturers' process of innovation is iterative.

While the information provided by manufacturers is most important during the monitoring process, it is not the only substance acquired by the engineering department. The variety of NASA information products were regarded by airline engineers as important sources for maintaining current awareness about state-of-the-art technology. The majority of the individuals interviewed regularly read NASA reports and technical briefs. In addition, many of the individuals interviewed participate on NASA technical committees or sponsored conferences. The subsidiary position of NASA information products in the monitoring process can be attributed to NASA's role as a patron of basic and applied research. NASA's efforts in these activities will ultimately benefit the airlines. However, the manufacturers--not the airlines--integrate NASA-generated knowledge and technology into aircraft systems. Thus, the primary audience for NASA products is the equipment manufacturers.

Investment Decision Process

The airline flight equipment acquisition process is complex, time consuming, and expensive. The process requires the cooperation of many of the departments within an airline. It is an

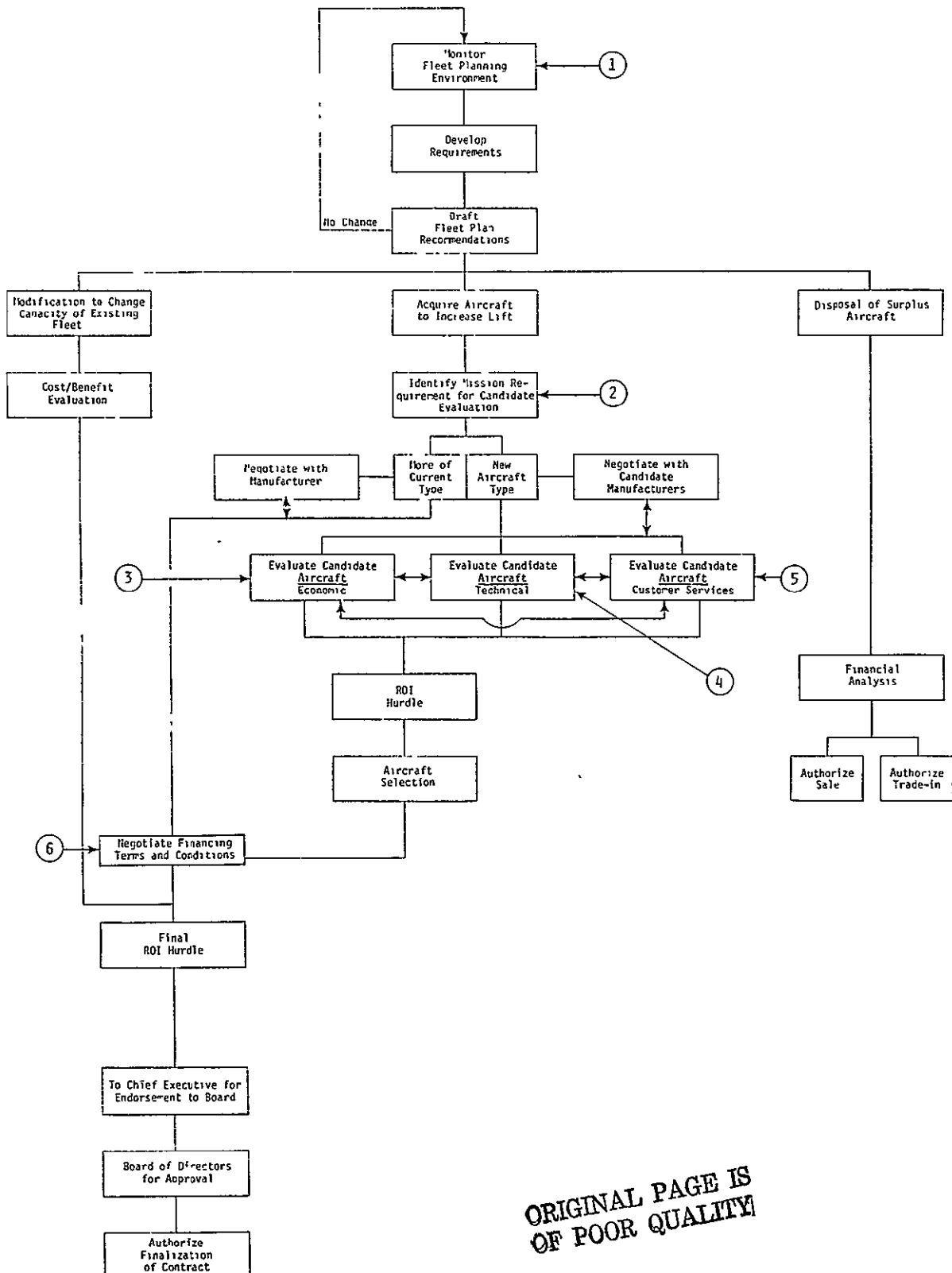
information-intensive activity with all efforts directed at reducing the risk associated with acquiring new technology. A descriptive model of the equipment acquisition process is shown in Exhibit 4-5.

The model indicates the process through which decisions concerning the flight equipment are made. The role of the engineering department in the equipment acquisition process is graphically illustrated in Exhibit 4-6. In addition, the relationship of the engineering department's functions to the manufacturers' process of innovation is indicated. The purpose of this exhibit is to indicate the loci of engineering activities with respect to the manufacturer's innovation process and the airline equipment acquisition decisionmaking process. The exhibit highlights these relationships by indicating the location of the engineering department in a hypothetical airline organization structure.

It is clear from this exhibit that the engineering department participates throughout the equipment acquisition process. The data collected for this project indicate that the airline's equipment acquisition activity transcends the activities shown in Exhibit 4-5. The engineering department activities pertinent to the decision process commence before the beginning of the universal process and continue beyond its last element. Engineering is active before the inception of the universal process since it is the technical liaison with equipment suppliers. The liaison activities occur whether or not the company is formally evaluating

Exhibit 4-5

UNIVERSAL DECISION PROCESS FLOW CHART



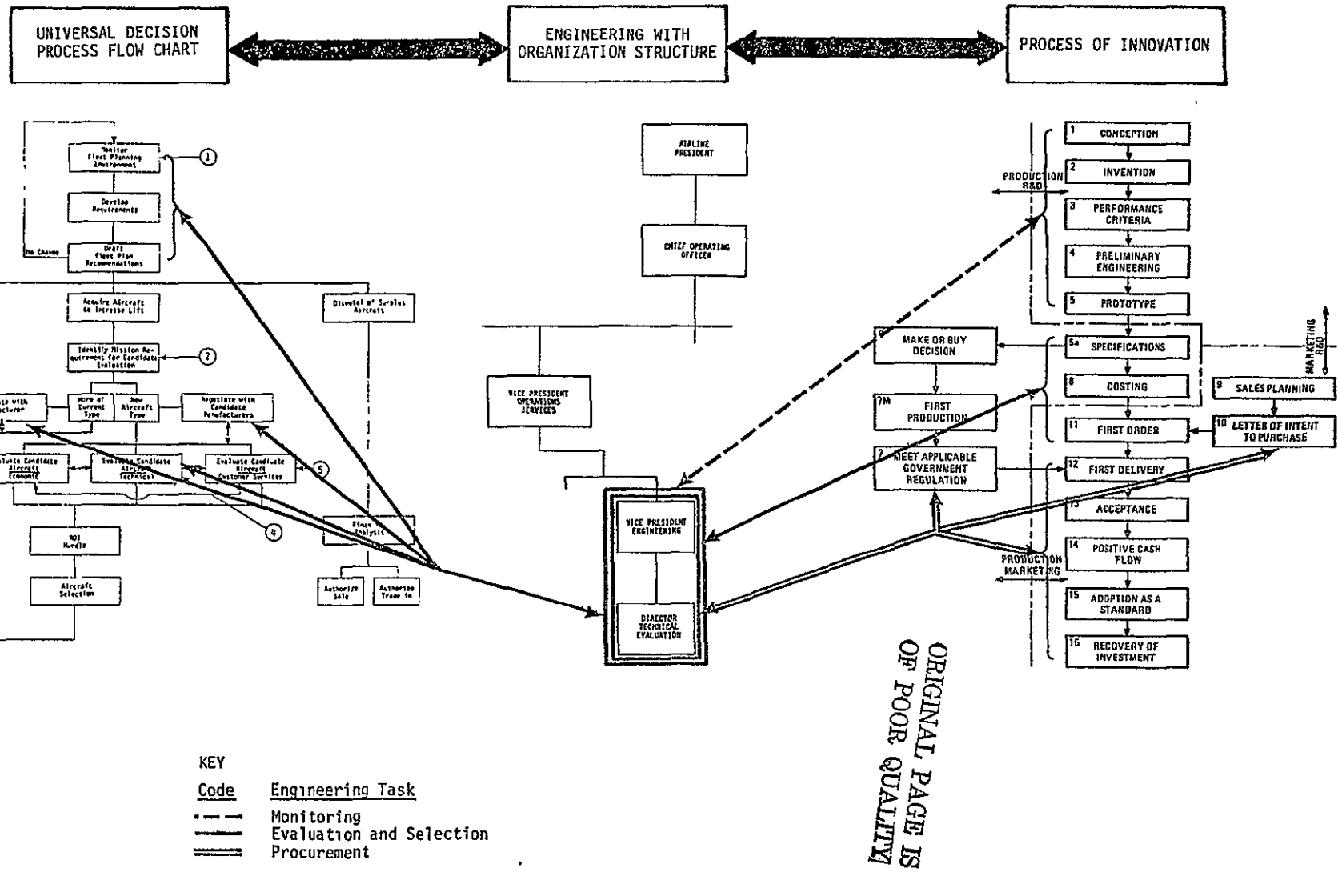
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Exhibit 4-5 (continued)

- 1 Competitive Fleet Analysis
High Time of Existing Fleet
Existing Load Factors
Market Forecasts
Economic Forecasts
Manufacturers Data
- 2 Size of Order
Special Operational Requirements
Ground Operational Requirements
Convertability
Delivery Timing
- 3 Unit Costs
Seat Mile Costs
Plane Mile Costs
Ton Mile Costs
Trade-in
Expected Break-even Load Factor
Used vs New
- 4 Airport Compatability
Performance Specifications
Plane Mile Costs
Seat Mile Costs
Commonality
Service Record
First Operator
U.S. Manufacture
Ability to Request Design Changes
Flight Operations Characteristics
Service Life
Design Concept
Number of Engines
After Sale Support
Parts Pool
- 5 Passenger Appeal
Wide Body
Service Features
First Operator
Number of Engines
- 6 Unit Cost
Interest Rate
Trade-in
Profit -
Investment Tax Credit
Depreciation Policy
Leasing Terms

Exhibit 4-6

INTERRELATIONSHIPS OF DECISION PROCESS WITH ENGINEERING ORGANIZATION WITH PROCESS OF INNOVATION



equipment for purchase. In addition, the engineering department also monitors production of the flight equipment to protect the interest of the airline. It should be noted the model developed in the following section concerns the acquisition of new technology flight equipment. Other acquisition scenarios will be covered later in this report.

Selection of Candidate Aircraft

The acquisition process begins when the marketing department (or perhaps fleet planning) perceives a possible need for additional and/or different flight equipment. The factors which influence or determine the carriers' needs for new flight equipment vary. New equipment may be required to replace uneconomic aircraft.¹ Further growth in existing markets, types of services and/or routes may necessitate new equipment acquisition. In addition, the data suggest that new aircraft are often acquired in response to the equipment purchases of other carriers.² However, the reason for aircraft acquisition does not normally influence the nature of the engineering analysis. Rather, the intensity of the engineering analysis is determined by uncertainty concerning performance of the candidate aircraft.

¹The airlines participating in this study employ structured monitoring programs for airframes and engines. The purpose of these programs is to determine whether the performance of the equipment has deteriorated to an unacceptable level.

²Most carriers interviewed conducted analyses of their competitors' fleets. For example, some personnel interviewed stated that their airlines initially acquired the B-747 as a competitive response to Pan American's procurement. An acquisition decision based on competitive pressure could be justified using the ROI criterion if the carrier was placed at a disadvantage without the new equipment.

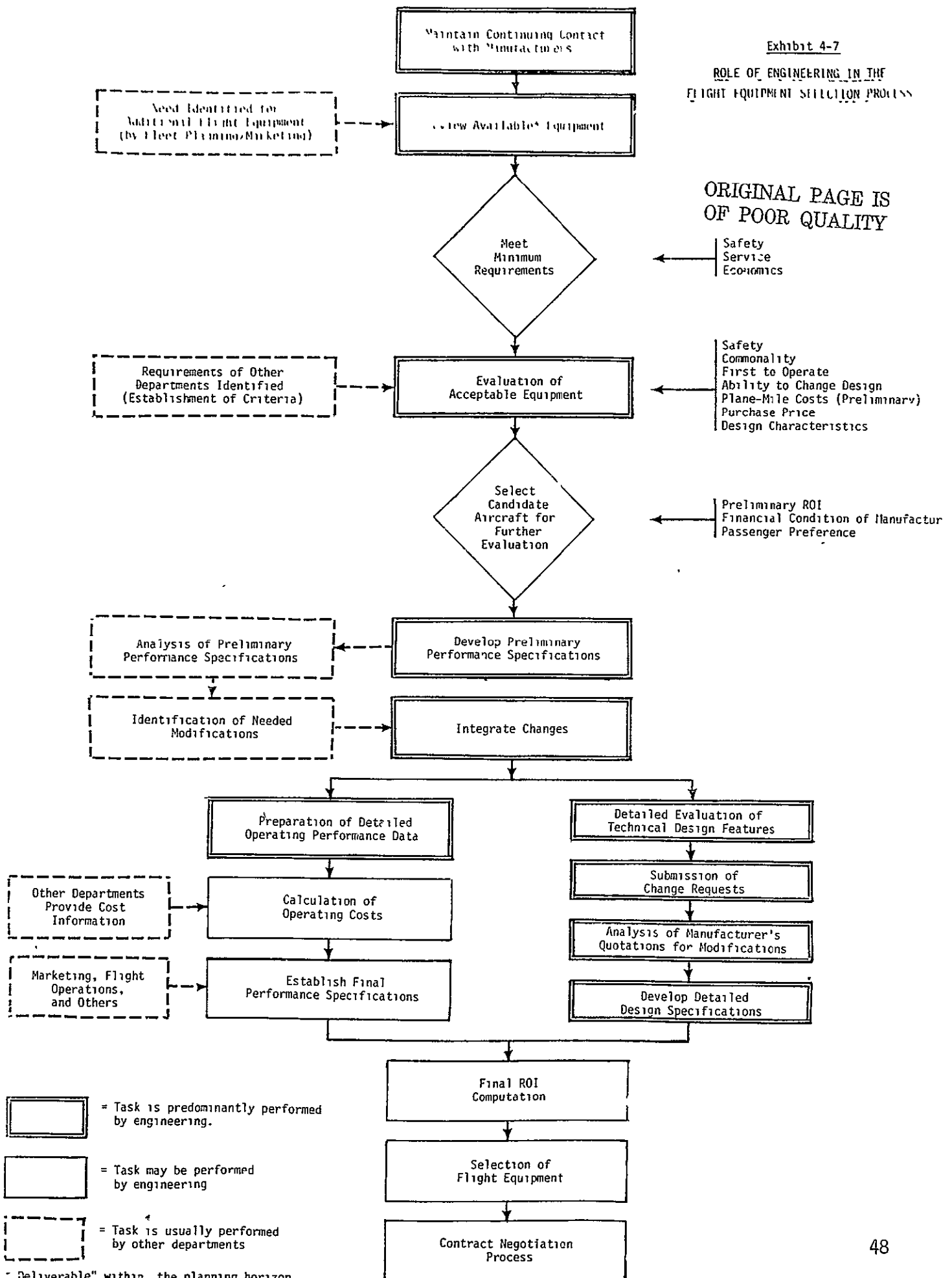
The activities of the engineering department in this process are shown in Exhibit 4-7. This diagram is a general representation of the process employed at all the airlines interviewed. The differences in the practices of each airline can be attributed to variations of authority accorded each engineering department. The flow chart distinguishes those functions usually performed by the engineering department from those tasks that in many cases are the responsibility of other departments. The flow chart also differentiates engineering tasks that are: (1) activities in support of cost estimates, and (2) technical analyses. The "role of engineering" in the equipment acquisition process as depicted by the flow chart is discussed below.

Maintain Continuing Contact With Manufacturers--Predominantly an engineering function, this element signifies the ongoing liaison between engineering and the manufacturer's technical representative. This "step" is not part of the actual decision process; rather, it is the monitoring function described in the first part of this section.

Review Available Equipment--Engineering identifies the equipment that will be available for delivery within the time horizon identified by marketing (or fleet planning). It evaluates the spectrum of available technology. Further, engineering indicates which aircraft (or other equipment) may be able to fulfill the carrier's needs. Engineering assembles preliminary operating and performance data for each candidate equipment. At this stage of

ROLE OF ENGINEERING IN THE
FLIGHT EQUIPMENT SELECTION PROCESS

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the decision process, it is not possible to determine whether any item will, in fact, meet the carrier's "needs."³

Meet Minimum Requirements--A preliminary engineering evaluation is conducted to determine whether prospective equipment meets minimum technical requirements.⁴ Such requirements are criteria comprised of those design features which must be embodied in the flight equipment and those which are unacceptable. Most of these criteria relate to safety factors; one engineer mentioned that passenger cabin doors must be of a plug design before an aircraft will even be considered for purchase. Other factors are also considered. For instance, an aircraft would be eliminated from further consideration for a feature subjecting the airframe to premature structural fatigue.

Evaluation of Acceptable Equipment--The evaluation of prospective flight equipment takes into account the following factors:

- capital costs,
- spares requirements,
- life cycle cost,
- support materiel,

³Bear in mind that a "need" for additional or replacement equipment exists provided that management determines that it can earn a profit on the change in the fleet. At this stage, such projections are preliminary, and will be the subject of the formal evaluation.

⁴Engineering often has a role in determining what these requirements will be. For example, when the need for ground proximity warning radar became evident, the avionics engineers from a number of airlines met to define the performance requirements of this equipment.

- provisioning,
- training,
- flight crew training,
- ground equipment,
- simulators,
- shop equipment,
- maintenance facilities,
- airport requirements.

Each of these factors is a distinct component of the overall economic impact of a new aircraft. The Universal Decision Process Flow Chart lists elements in the decision process where each of these factors are considered.

Engineering participates in the assessment of many of these factors including: spares requirements, capital costs, life cycle cost, support materiel, shop equipment, and maintenance facilities. The other factors which engineering may address depend upon the individual company. A typical procedure used to measure these factors involves a joint evaluation, drawing upon the staffs of the engineering and operating departments. For example, the estimation of spares requirements is carried out with the assistance of maintenance personnel.

Less quantifiable factors also enter the purview of engineering: safety, commonality, being the first to operate, ability to change design, and design characteristics. These factors require expert judgments by the engineers.

Select Candidate Aircraft for Further Evaluation--Once the previous element is completed, the decisionmakers are well versed in the choices available to them. These individuals are the senior executives responsible for making recommendations for modifications of the fleet. They choose those candidate aircraft which warrant a thorough assessment.

Develop Preliminary Performance Specifications--The engineering staff develops preliminary performance specifications for the flight equipment which include: range, payload, fuel consumption, and out-of-service maintenance requirements. It is the engineering department's responsibility to provide projections of the equipment's performance, which are particularly important to other departments in their evaluations.

This engineering task also includes development of data to be used by other departments to compute costs. These data are projections of crew requirements, maintenance equipment, towing vehicles, and other physical accommodations required of the airline. These projections are relayed to appropriate operating departments.

Integrate Changes--Various operating departments must work with the engineering staff in the calculation of the above mentioned factors. Engineering explains how the new equipment will function. The operating department's analyst projects the impact of this new function.

Two distinct series of activities occur after the integration of changes. The first is a series of steps leading to the

computation of the final performance specifications. Second, a process is undertaken in which modifications of the design are developed.

Preparation of Detailed Operating Performance Data--Engineering must finalize its estimates of the performance characteristics of each candidate. Its projections, developed in part from manufacturers' models and in-house models (see Chapter 3), are completed at this time. The design of the aircraft is nearly finalized (see below); now engineering must generate the hard estimates of operating data used to compute costs.

Calculation of Operating Costs--On the basis of the detailed operating performance data, estimates of expenses can be performed. These estimates are the total range of costs that must be incorporated into the rate of return-on-investment computation discussed below.

The specific department responsible for converting the projections into costs varies among the carriers. In some companies, engineering provides either the fleet planning or the finance department with the necessary data to compute cost estimates. In others, engineering actually converts the operating data into costs in conjunction with the appropriate operating departments.

Establish Final Performance Specifications--This element is tied in closely with the next four elements that concern the design modifications of the equipment. "Final" performance

specifications are simply the last projections of the equipment's output and operating parameters. They are based upon the detailed design specifications chosen by the selection team (discussed below).

After this element, the flow chart progresses on to a final ROI computation. However, a series of additional steps are required first. They form the process leading to the finalization of the design specifications of the equipment.

Detailed Evaluation of Technical Design Features--In addition to developing performance specifications, engineering performs an analysis of the technical features of each acquisition choice. Earlier in the selection process, engineering verifies that each item of equipment under consideration for purchase meets a set of minimum technical criteria.⁵ Further technical evaluation is necessary in order to identify the superior choice with respect to technical design and performance. Engineering personnel evaluate each potential purchase across hundreds of specific features, using various rating systems. Although this technical evaluation is treated as only a single consideration in the final decision, it was found that engineering's opinion is of the greatest importance when two candidate aircraft are close

⁵For example, the original design of the Rolls Royce RB-211 engine included a composite material fan blade (the Hyfil blade). Because of uncertainty associated with the performance of this fan blade, certain airlines required that Rolls Royce also pursue the development of a titanium blade. The titanium blade would have been substituted if the Hyfil fan blade did not perform satisfactorily. This contingency plan was specified in the contract for the engine acquisition. In fact, the titanium blade was finally used for this engine.

substitutes. For example, the differences between a B-727-200 and a DC-10 are so substantial that it is unlikely that the final selection will be affected significantly by engineering's technical ratings. When the choice is between very similar aircraft, however, such as the L-1011 and DC-10 wide-body trijets, marketing and flight operations may have no strong preference. Thus, the recommendation of the engineering department, based on their assessment of the relative quality of competing designs, becomes the primary differentiating factor.⁶

The evaluation of foreign technology is conducted in a similar manner. However, the interviews identified some reluctance toward the adoption of foreign technology. The discussions indicated that some carriers have had unsatisfactory experiences with foreign equipment. The most frequent source of displeasure was the lack of after-sale support available from foreign manufacturers.⁷ Distance was also cited as a factor hindering the adoption of foreign technology. The engineering staffs often visit the manufacturer as part of the evaluation. The expense and time required for overseas visits and data acquisition have been justified only for select technology. Another barrier to the acquisition of

⁶A situation such as this can also lead to price reductions by the manufacturers. This was alleged to have occurred in the case of the highly competitive DC-10 and L-1011 aircraft.

⁷One carrier cited long delays in obtaining parts for the Rolls Royce "Tyne" engine.

foreign technology is the import tariffs. Tariffs influence the price of aircraft and replacement parts. One carrier purchased blueprints for various parts of a foreign aircraft so that it could produce these parts, thereby avoiding the effect of the import duty. However, the discussions also indicated that this bias against foreign manufacturers was lessening. For example, foreign manufacturers have improved the accuracy and level of detail available in performance data. Two carriers cited these improvements as a positive step towards the acceptance of foreign technology in the U.S. market.⁸

Submission of Change Requests--As the evaluation team nears the selection decision, engineering works toward development of the final design of the equipment prior to signing a purchase contract. This design is achieved as a result of a process in which the carrier and the manufacturer precisely define the product to be delivered.⁹ The change request is the key to this process. It consists of a requested price quotation on an alteration of the standard design submitted by the manufacturer. One

⁸One carrier's engineering staff was performing an in-depth evaluation of a foreign manufactured airframe at the time of the interview. It was clear that their greatest concern was after-sale support.

⁹It was noted in the interviews that two carriers, once they had made commitments to purchase the DC-10, agreed on a common configuration for the aircraft. This was done to minimize the acquisition cost of the aircraft. The manufacturer did not have to develop a unique configuration for each carrier and could spread development costs over a large number of nearly identical airplanes.

is submitted to the manufacturer when a department in the airline perceives that a modification may be necessary to meet a special need.

Engineering is the prime conduit of the change request because it is the principal liaison with the supplier insofar as technical matters are concerned. (Other departments communicate directly with the manufacturers with regard to other issues.)

Analysis of Manufacturer's Quotations for Modifications--

Numerous change requests are submitted to the manufacturer and quotations received. Engineering and each appropriate operating department consider each quotation made by the manufacturer. They determine whether it is worthwhile to incur the incremental cost required to acquire the modification.¹⁰ When the actual sale is consummated, the product purchased is likely to incorporate scores of modifications from the standard design.

Develop Detailed Design Specification---After selection of modifications, engineering prepares the final design specifications. A price for the aircraft is computed.¹¹

Final ROI Computation--The selection team now has all of the necessary information required to make its final calculation of ROI.

¹⁰An analysis is also performed to determine whether it would be more cost effective for the carrier or a third party to perform certain modifications.

¹¹First buyers of new technology flight equipment are often granted price reductions by the manufacturer. This is done to promote the introduction of this equipment.

This step produces a computation of the profits expected from each of the final candidates.

Selection of Flight Equipment--This step in the decision process draws upon engineering's data, but engineering personnel usually do not participate in the final decision. The engineering department's role is subordinate to other airline departments. However, engineering's recommendation carries considerable weight. Indeed, vigorous objections by engineering to design features in one candidate could tip the balance to another candidate.

In a minority of the carriers interviewed, engineering was an equal participant in the selection decision. Carrier A's Chief Technical Evaluator works on equal terms with a senior marketing executive and a financial executive. They make a joint decision and recommend it to the Senior Vice President who then makes the final decision.

Contract Negotiation Process--The negotiation process begins with the submission of change requests by the airline. The buyer and seller engage in negotiations to settle the final configuration and price of the technology. Engineering usually plays a support role in the process of negotiations by drafting the technical specifications.

The engineering departments of some carriers are included on the contract negotiation team because they developed the detailed specifications.¹² Engineering representatives may also

¹²In Carrier A, the person responsible for the technical (including engineering) evaluation is solely responsible for contract negotiations.

help work out some of the warranties and penalties built into the contract.¹³

Conclusion

After the sales contract is signed, additional support is required from the engineering department. An engineer may be stationed on the vendor's premises to inspect the work in progress, and to verify that the equipment meets all specifications. On-site inspection is so important that extra engineers are routinely assigned temporarily to the factory.¹⁴

Engineering Role in Different Types of Acquisitions

The model developed (Exhibit 4-7) in this study describes the engineering evaluation process for new technology flight equipment. However, frequent investment decisions concern the acquisition of either an existing or derivative technology. The engineering analysis required for this type of decision is less exhaustive than that described in the model (Exhibit 4-7). If an airline is acquiring additional equipment of a type already in its fleet, a formal technical analysis is not normally performed (Exhibit 4-5)

¹³The engines for both the DC-10 and B-747 were covered by such a contract. In fact, the manufacturer had to make payments because some of these engines did not perform as warranted with respect to fuel consumption.

¹⁴In addition, the vendor stations its own technical representatives on the premises of the carrier's maintenance base in order to provide ongoing assistance and consultation with regard to the products purchased by the carrier. However, these representatives do not interface with the people who buy aircraft, but rather the people who maintain them.

since a formal analysis was performed when the aircraft first entered the fleet. The technical analysis in this case focuses on incremental changes in the technology which have been adopted subsequent to the initial acquisition. In addition, the carrier has an extensive data base which describes the performance of this equipment type in its fleet. These data supplant the need for projections of estimated equipment performance and reliability. If an air carrier purchases equipment of a type operated by other airlines, the technical analysis is based upon operating data procured from the other airline. Engineering's primary task is to examine and modify the data to ensure it reflects their operations. Informal contacts with the engineering and maintenance departments of other airlines are utilized to gather information on the maintainability and reliability of the prospective equipment.¹⁵ The products of the technical analysis for existing, derivative, or new technologies are similar to one another. The product similarity occurs because an airline needs the same information for any flight equipment investment decision.

As noted above, there are three general scenarios which can be used to describe aircraft acquisition. The airline can sponsor new technology, purchase existing equipment of a type

¹⁵Although airlines are competitors, an incentive for cooperation exists. Purchases of the same equipment by other airlines promote better availability of parts, lower unit costs, the ability to order more of the same in the future (keeping the production line open), etc..

not in its fleet, or purchase equipment of a type already in its fleet. The analysis used by the airline will vary for each of these scenarios. The choice of analysis technique reflects the level of uncertainty inherent in a particular scenario.

The risk is greatest when an airline sponsors a new technology. The data available to evaluate the aircraft are generally optimistic estimates from the manufacturer. Therefore, economic calculations are not based on actual experience. The purchase of equipment in use by other airlines reduces the risk. Historical data can be obtained based upon actual operations. However, the data does not reflect the airlines own experience. Procuring more of an aircraft type in the airline's fleet represents the minimum risk. The carrier can base the economic calculations on historic data which is derived from his own experience.

The specific nature of the engineering analyses used for each scenario is illustrated in Exhibits 4-8 and 4-9. The types of analyses performed for acquisition of an entire aircraft are shown in Exhibit 4-8, and those for acquisition of components only are shown in Exhibit 4-9. These matrices indicate whether the analysis is conducted by all carriers. They also indicate if the analysis is formal or informal. Multiple entries in the matrix cells indicate that the analysis practices vary among the carriers interviewed.

The matrices indicate that the level of risk determines whether a formal analysis will be conducted. For instance, in the

Engineering Dept. Functions		Normal Operation	Acquisition		
			Sponsoring New Technology Flight Equipment	Existing Flight Equipment not in Airline's Fleet	More of Type Already in Fleet (or Derivatives)
Aircraft Acquisition Continuous Activities	Monitoring State of Art	SF-SI	SF - SI	SI	N
	Technical Evaluation of S.O.A.	SF-SI	SF - SI	N	N
	Asking Suppliers Questions of S.O.A. for Technical Response	AI	AI	SI	SI
	Standard-Setting Activities	SF-SI	SF - SI	SI	N
	Intelligence	AI	SI	SI	
Aircraft Acquisition Specific Acquisition	Technical Evaluation Performance		AF	SF - SI	SI
	Maintenance		AF	SF - SI	SI
	Fleet Compatability		AF	SF - SI	N
	Landside Interface Compatability		AF	AI	N
	Engineering Economics		SF - SI	SF - SI	SI
	Detailed Specifications		AF	AF	SF - SI
	Operating/Performance Guarantees		SF	SF	SF
	Quality Control		AF	AF	SF - SI
Normal Activities	Fleet Engineering	AF			
	Plant Engineering	SF			
	Maintenance Monitoring	SF - SI			
	Aircraft Inspection	SF - SI			

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Key
AF = All Carriers Perform Formal Analysis
AI = All Carriers Perform Informal Analysis

Key

AF = All Carriers Perform Formal Analysis
 AI = All Carriers Perform Informal Analysis
 SF = Some Carriers Perform Formal Analysis
 SI = Some Carriers Perform Informal Analysis
 N = No Direct Analysis Performed

No Entry = Not applicable to this function

Exhibit 4-8

Engineering Functions for Different
 Types of Flight Equipment Acquisition:
 Entire Aircraft

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Engineering Dept. Functions		Normal Operation	Acquisition		
			Sponsoring New Technology Flight Equipment	Existing Flight Equipment not in Airline's Fleet	More of Type Already in Fleet (or Derivatives)
Aircraft Acquisition Continuous Activities	Monitoring State of Art	SF-SI	SF - SI	SI	N
	Technical Evaluation of S.O.A.	SF-SI	SF - SI	N	N
	Asking Suppliers Questions of S.O.A. for Technical Response	AI	AI	SI	SI
	Standard-Setting Activities	SF-SI	SF	SI	N
	Intelligence	AI	SI		
Aircraft Acquisition Specific Acquisition	Technical Evaluation Performance		AF	SF - SI	SI
	Maintenance		AF	SF - SI	SI
	Fleet Compatability		SF - SI	AI	N
	Landside Interface Compatability		AI	AI	N
	Engineering Economics		SF - SI	SI	SI
	Detailed Specifications		AF	SF - SI	SF - SI
	Operating/Performance Guarantees		SF	SF	SF
	Quality Control		AF	AF	SF - SI
Normal Activities	Fleet Engineering	AF			
	Plant Engineering	SF			
	Maintenance Monitoring	SF - SI			
	Aircraft Inspection	SF - SI			

Key

AF = All Carriers Perform Formal Analysis

AI = All Carriers Perform Informal Analysis

Key

AF = All Carriers Perform Formal Analysis
 AI = All Carriers Perform Informal Analysis
 SF = Some Carriers Perform Formal Analysis
 SI = Some Carriers Perform Informal Analysis
 N = No Direct Analysis Performed

Exhibit 4-9 No Entry = Not applicable to this function

Engineering Functions for Different
 Types of Flight Equipment Acquisition:
 Components Only

last column of each exhibit only three items are subject to formal analysis by some carriers in the equipment acquisition process. However, in the high risk category, sponsoring new technology flight equipment, all but one item is subject to formal analysis.

Factors Influencing the Diffusion of New Technology

The data collected in the interviews indicated engineering's perception of fifteen potential factors influencing the diffusion of new technology. These factors are:

- technical risk,
- economic risk,
- capital cost,
- maintenance cost,
- life cycle cost,
- improvement over alternative,
- capital or labor saving,
- mission need,
- impact of increased direct operating cost,
- organizational structure,
- adaptation to the change,
- poor information,
- organization size,
- regulation, and
- fleet commonality.

The matrix in Exhibit 4-10 summarizes the relative importance of each factor on the diffusion of technology. The principal influencing factors, as perceived by the engineering departments, are:

Exhibit 4-10

FACTORS INFLUENCING THE DIFFUSION OF TECHNOLOGY
AS PERCEIVED BY ENGINEERING DEPARTMENTS

BARRIER	TECHNOLOGY CLASS	COMPONENT	MAJOR SYSTEM
Risk--Technical		1	1
Risk--Economic		2	2
Capital Cost		1	1
Maintenance Cost		1	1
Life Cycle Cost		1	1
Improvement over Alternative		2	1
Capital Labor Saving		2	2
Mission Need		2	1
Impact of Increased DOC		2	1
Organizational Structure		2	2
Adaptation to the Change		2	2
Poor Information		2	2
Organization Size		2	2
Regulation		2	2
Fleet Commonality		1	2

Key

1 = Clearly an influential factor

2 = In some cases, an influence may exist

- technical risk,
- economic risk,
- capital cost,
- maintenance cost,
- life cycle cost, and
- fleet commonality.

In the acquisition of a major system, the principal barriers to diffusion include:

- technical risk,
- capital cost,
- maintenance cost,
- life cycle cost,
- the technology is not an improvement,
- the technology does not meet airlines' needs,
- the technology increases direct operating cost.

5. CONCLUSIONS

This section contains a summary of the principal findings of this report.

- ° The main conclusion of this study is that engineering activities permeate, but do not dominate the airline flight equipment decision process. That is, the products of engineering activities are necessary but not sufficient to complete the decision process. In addition, the role of the engineering department in the flight equipment decision process varies in each airline. However, the technical tasks required of engineering departments are consistent. Further, while the engineering department is actively involved in the flight equipment acquisition process, it is not usually involved with the acquisition decision.
- ° The principal criterion for the flight equipment acquisition decision is return on investment. However, when different aircraft are virtual substitutes for each other in terms of operations, marketing, and finance, then the importance of ROI as the decision criterion is diminished. Therefore, the importance of engineering criterion in the decision increases.
- ° There are two generic types of engineering activities which influence the flight equipment decision process: monitoring and evaluation. The monitoring activities

include the acquisition and exchange of information which allows an airline's engineering department to maintain awareness of state-of-the-art technology. In addition, monitoring activities provide a means for the airlines to inform equipment manufacturers of future airline need. The evaluation process is the series of activities which the engineering department conducts in support of the airline flight equipment acquisition process. The process is graphically illustrated in Exhibit 4-7.

- ° The principal sources of information for the airline engineering departments in the monitoring process are the manufacturers of equipment. Subsidiary information sources include NASA publications and conferences, among others.
- ° The engineering department is the principal communication channel for technical information between:
 - the airline and equipment manufacturers,
 - the airline and government agencies,
 - the airline and other airlines,
 - the airline and technology-oriented trade associations.

The engineering department's communication channel function occurs in both the monitoring and evaluation processes. The engineering department is proactive,

i.e., initiating contacts and communication during the monitoring process. However, the engineering department is reactive to the needs of other departments during the flight equipment decision process.

- The level of risk associated with an equipment acquisition determines whether formal or informal analyses will be conducted by the engineering department.
- The principal factors influencing the diffusion of new technology via the engineering department for both component systems are:
 - technical risk,
 - economic risk,
 - capital cost,
 - maintenance cost,
 - life-cycle costing.

In addition, an important consideration in the acquisition of component technology is fleet commonality.

Appendix

ENGINEERING DECISION PROCESS QUESTIONS

The purpose of this questionnaire is to identify the role of the engineering department in aircraft investment decisions. The investments include the purchase of new aircraft, the modification of current aircraft, and the disposal of current aircraft (including leasing). It seems reasonable that engineering inputs to the decisionmaking process could be the result of both day-to-day monitoring of the state of the art and evaluation of specific technology and/or aircraft in conjunction with a particular decision. Therefore, the questions for this interview can be divided into three categories:

1. Procedures for routine monitoring of the state of the art.
2. Procedures for participation in a specific equipment investment decision.
3. Examples taken from your experience that might be illustrative.

Routine Activities

In staying abreast with the state-of-the-art:

- ° Does your department analyze data, information, etc., and note for possible use in a future decision process?
- ° How much of such analysis is done formally and how much informally?

- What procedure is followed for formal analysis?
- Who is responsible for identifying technological areas that may be of interest?
- How much time is spent on such activities?
- From what sources does your department acquire information for general analysis of the state of the art?
 - a. Formally?
 - b. Informally?
- What constitutes a good source?
- If government publications or other government sources are useful, what makes them so? What specific government sources are used? Do they include NASA publications?
- Does information about possible technological areas to investigate ever originate from other departments?
- What, if any, foreign sources do you use and why do you find them useful?
- By what criteria do you evaluate the potential usefulness of technological developments (i.e., travel time, payload-range, operating cost, passenger appeal, safety, noise, air pollution)?
- Have these criteria changed over time?
- Are there certain classifications of new technology that you consider more worthy of consideration than others,

or do you evaluate everything that could conceivably be of advantage to your company?

- How significant must findings be in order to be reported out of the engineering group?
- To which other departments are such findings reported, and by what criteria are they evaluated by these departments?
- Do these departments ever check outside sources to verify the findings?
- Do the activities of any other departments parallel those of engineering in staying abreast of new developments?
- When findings are reported, what is the nature of the "feedback"?
- What kinds of contact do you have with airframe and engine manufacturers?
- With whom in these companies do you make contact?
- Does your airline provide inputs to manufacturers as they develop technology? If so, is it a routine matter or does it only occur when a specific purchase is being considered? Do you actively cooperate in the development or only evaluate technologies presented by the manufacturers?
- Who actually contacts the manufacturers to provide them with these inputs?
- Do the same people provide inputs to the government and NASA in the same manner?

- ° Is there any way that contact with manufacturers could be improved?
- ° Recognizing the competitive nature of the commercial air carrier business, how would you describe cooperation between your engineering department and those of other airlines in the evaluation of new technology?
 - a. Frequent, informal cooperation.
 - b. Only through formal meetings and symposia.
 - c. Only in times of crisis.
 - d. No cooperation at all.
- ° Are there any restrictions on your department's activities with regard to new technologies? If so:
 - a. What are they?
 - b. What is their purpose?
 - c. Who imposes them?
 - d. Do they impair your department's performance? How?
- ° Do your routine activities enter anywhere on the accompanying flow chart?

Contribution to Specific Equipment Investment Decisions

In answering the following questions, references to the accompanying flow chart will be most helpful.

- ° As an airframe/engine increases its operational life, its performance will start to deteriorate, even given the

rigorous preventative maintenance programs of the air carriers. Is there a structured monitoring process your department uses to record individual airframe/engine performance, cost, or particular preventative maintenance history, etc.? Or is this applied to the aircraft fleet or portions of the fleet?

- What exactly does this monitoring process examine?
- Where would you place this process on the flow chart?
- What factors other than age enter into the decision to monitor a given aircraft/engine?
- By what criteria does the engineering department decide to inform other departments of the results of such monitoring?
- Which departments are informed of this monitoring?
- How do they respond? Do they usually require more information before initiating a plan to correct the situation?
- Usually, a plane is bought in keeping with certain parameters, perhaps as part of a 5-10-15 year master fleet plan. Are there instances where you might recommend retiring an aircraft early (for a reason other than excess capacity)? What are the factors in the decision and what role would your department play in deciding how to retire these aircraft?
- Does your department ever decide on its own (i.e., without a specific request from other departments) to evaluate the

technical aspects of the possibility of modifying existing aircraft/engines?

- Does your department ever evaluate the technical characteristics of various aircraft currently in service (excluding your fleet) on its own?
- Which department usually initiates a routine equipment purchase?
- How does the routine procedure compare to the attached flow chart?
- Who actually elicits the engineering department's analysis of available equipment?
- Which department decides when to elicit an engineering evaluation of the following options:
 - a. Sponsoring new design.
 - b. Buying more of an existing aircraft type.
 - c. Buying more of an existing type not found in your current fleet.
 - d. Buying and modifying an existing type.
 - e. Buying used aircraft.
 - f. Modifying existing aircraft.
- For each of the above options, who (in the engineering department) performs the evaluation?
- If and when you evaluate used aircraft, do you attempt to verify previous maintenance and service records?

- Is there a standard step-by-step procedure used to evaluate the technological aspects of an aircraft that is being considered for purchase?
- How does this procedure differ from the procedure for keeping up with the state of the art?
 - a. If you use different sources, what are they?
 - b. Are sources useful for the same reason?
 - c. By what criteria do you evaluate technology? Who sets them? Do they change over time?
- Are government sources important in this type of investigation? If so, which ones? In particular, are NASA sources useful? Why or why not?
- By what criteria are people assigned to a project whose purpose is to evaluate a new technology?
- Who determines the level of effort for such projects? Are they within the engineering department?
- When do senior engineers become involved?
- Are there typically stages in such projects on which more and more effort is allocated as the technological area "passes the importance test" at each stage? Is there a formal set of stages?
- Do you develop models to simulate aircraft performance?
- Do you depend on manufacturer's models? If not, whose do you depend on?

- What reliance do you place on manufacturer's data? For example, performance estimates, D.O.C.'s, etc., are prime examples where, in practice, aircraft engines sometimes tend to not meet manufacturer's claims when placed in operation. Airframe manufacturers generally use ATA standard methods of estimating costs and performance. Do you use the same methods?
- If the figures derived by your department vary with the manufacturer's estimates, is this because you tend to use data applicable to your airline as opposed to the industry as a whole? For what other reasons might the figures differ?
- With foreign manufacturers becoming more aggressive, do you consider their products in the same way you analyze domestic products, or is there a factor either pro or con applied to foreign equipment and technology?
- Are foreign suppliers as attentive as their domestic counterparts?
- If you know that a competing carrier also requires a similar new design of aircraft, is there any attempt to form a combined team to advise the manufacturer in order to achieve commonality, price requirements, etc., or is the reverse more likely to occur with each airline consulting individually with the same manufacturer to obtain a perceived competitive edge, etc.?

- When evaluating an aircraft for which other carriers have already placed orders, does the expected position on the "waiting list" for delivery have an effect?
- What criteria must be met in order for your department to specify the inclusion of new technology in an aircraft design as a condition of purchase?
- Does your airline have sufficient "clout" to make such a demand? What is the minimum sized airline necessary to do so?
- What is your perception of the commitment required from your airline in order for a manufacturer to change his basic airframe configuration, air frame/engine combination, etc. to accommodate your specific needs?
- Considering the discussion so far, how would you amend the attached flow chart to include the engineering department in more detail?

Illustrative Examples

It would be very helpful if you could provide some examples of the process by which you have evaluated specific aircraft and technologies. If these examples covered a range of time from the early 1960's to the present, it would aid in illustrating the evaluation of your decisionmaking process.